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Evaluation of Methods for Automatically Determining the Fitness of Currency

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Progress Report covering the period
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Note
The results contained and the conclusions reached in
this progress report are preliminary. Final results
and conclusions will be presented in the final report.

Table of Contents

1. Summary

This report covers work on three parts of the methodology of assessing the fitness of currency while it is in motion through a transport system. These three areas of activity are: 1) development of a method of detecting the presence of tape on a bill, 2) development of a method of assessing the structural integrity of a bill, and 3) development of a method of verifying the denomination of a bill.

The work on tape detection is a continuation of previous work where we found that it is possible to detect the change in thickness due to the presence of tape on a bill with a simple contacting, moving-arm device. This device consisted of a small, narrow roller bearing which was spring loaded against a driving wheel of a transport mechanism. An alternative approach is to use a contacting arm with a low enough inertia that an adequate speed of response can be obtained without generating frictional forces which impede the motion of the bill. This approach to thickness measurement gives very noisy signals due to the engraving of the printed bills. The sensor is sensitive to the apparent thickness of the bill because it is not able to iron out indentations in the paper due to the intaglio printing process. These apparent variations in thickness are of the same order of magnitude as the thickness of tape which would be found on a bill.

Defects in the structural integrity of a bill such as tears, holes or missing pieces can be sensed optically by either reflection or transmission measurements. A choice between the two depends largely upon which type of measurement is easiest to fit onto a currency handling transport. The transmission method requires access to both sides of the path of the bill through the transport. The reflection method requires access to only one side. The detection scheme consists of multiple light sensitive detectors which each scan a small portion of the bill parallel to the direction of motion of the bill. The detectors are mounted on a line perpendicular to the direction of motion so that the entire bill is scanned as the bill moves through the transport. This report describes circuitry which combines the outputs from the multiple

detectors into a single indication of whether or not a bill
is structurally intact. Each detector output is converted
into a bi-level signal by comparing its instantaneous analog
value with a threshold value. The bi-level signal is high
if the bill does not interrupt the light beam and it is low
if the bill does interrupt the light beam. The combination
of the bi-level signals is described by one of three
possibilities: 1) all the bi-level signals are high, 2) all
the bi-level signals are low, or 3) some are high and some
are low. The first case describes the situation where no
bill is being scanned. The second case describes the
situation where the portion of the bill being scanned is
structurally intact. The third case is the situation where
the detectors indicate the presence of a defect in the
portion of the bill being scanned. The bi-level signals are
input into logic circuitry which triggers an indicator
whenever the third case occurs. The circuit also compares
the time duration of the second case to insure that the bill
is the correct length and triggers the indicator if it is
not. This trigger signal may be used to direct the
transport to route that bill to the appropriate output
pocket.

The verification of denomination is very similar in
nature to optical character recognition and pattern
recognition. Entire notes have been scanned with a document
scanner which moves a small spot of light over a stationary
photographic negative of the document. Both the front and
back sides of a one, five, ten and twenty dollar bill have
been recorded in a form suitable for entry into a computer
so that different comparison techniques can be analyzed.
Our preliminary results show that the denomination of a
bill, under laboratory conditions, can be determined by
using a masking technique where the light reflected from a
bill is shown through negative masks of the different
denominations. Under ideal conditions of perfect
registration and bill condition, no light will get through
the negative mask of the correct bill and considerable light
will come through all the other masks. When conditions are
less than ideal, the correct denomination can still be
determined by picking the mask that allows the minimum
amount of light through.

2. Tape Detection

We reported previously (1) that it is possible to
detect the change in thickness due to the presence of tape

on a bill with a simple contacting, moving arm device. This device consists of a small, narrow roller bearing mounted on a short shaft which is free to pivot. The bearing is spring loaded against a drive wheel of a transport mechanism. When a bill passes between the roller bearing and the driving wheel, the bearing is deflected an amount equal to the thickness of the bill. The speed of response of the device is related to the strength of the spring and the inertia of the roller bearing. It was found that the inertia of the bearing is great enough that a strong spring is needed to obtain the necessary speed of response. At the same time, the strong spring force makes it mandatory that a roller bearing be used to contact the bill because the frictional forces from a non-rolling contact would greatly impede the passage of the bill through the transport.

An alternative approach is to use a contacting arm with low enough inertia so that an adequate speed of response can be obtained without the use of a strong spring. Then the frictional force impeding the passage of the bill will be low. A phonograph cartridge is ideally suited for this purpose; it features an extremely high speed of response even with a spring strength a thousand times less than that required for the roller bearing device.

There are two basic types of phonograph cartridges, monaural and stereo. The monaural cartridge is sensitive to horizontal motion of its stylus and the stereo cartridge is sensitive to both horizontal and vertical motions of its stylus. It is much easier to mount the cartridge so that the bill deflects the stylus vertically. Therefore, the stereo cartridge is the preferred detector. A stereo cartridge has two separate outputs which correspond to the left channel and the right channel in a stereo system. The signal due to vertical motion of the stylus is present in both channels and so is the signal due to horizontal motion of the stylus. The signal in one channel is the sum of the horizontal and vertical components while the signal in the other channel is the difference of the two components. This can be expressed algebraically as

$$e_1 = e_h + e_v \qquad (1)$$

$$e_2 = e_h - e_v \qquad (2)$$

where e_1 is the voltage at one output,

e_2 is the voltage at the other output,

e_h is the voltage generated by horizontal motion
of the stylus,

e_v is the voltage generated by vertical motion
of the stylus.

The vertical component is found by subtracting equation (2)
from equation (1) and rearranging:

$$e_v = \frac{e_1 - e_2}{2} \tag{3}$$

The signal e_v is proportional to the motion of the stylus,
but it is not sensitive to the position of the stylus. This
is equivalent to saying that the signal is ac coupled and
has no response to dc signals. Figure 1 shows the type of
response obtained when a bill deflects the phonograph
stylus. Motion of the stylus only occurs when there is a
change in thickness and the voltage e_v is non-zero only at
these points. An electrical signal which is proportional to
the thickness of the bill can be obtained by integrating the
signal e_v.

$$e_t = \quad\quad e_v \; dt \tag{4}$$

where e_t is a voltage proportional to the thickness of the
bill, T is an integrating period, and A is a constant.

Figure 2 is a schematic of the circuit used to measure
the thickness of a bill while it is in motion. The outputs
e_1 and e_2 are connected together such that the output,
designated e , is the difference between the two signals.
This signal is fed to an RC filter which integrates the
signal and then the integrated signal is amplified.

The force required to deflect the phonograph stylus is
quite small and the bill must be held down as it moves
through the measurement area to avoid deflections of the
stylus which are caused by effects other than a true change
in thickness. The signal obtained from a taped piece of
bond paper moving through the measurement area is shown in
Figure 3(b). The change in thickness due to the tape is
clearly visible in the middle of the waveform. This
measurement was made at a speed equivalent to a rate of
twenty bills per second. Figure 3(a) shows the signal
obtained from a taped bill under the same conditions. It is
still possible to discern the presence of the tape but the
signal is much noisier; some of the peaks approach the

4

signal level due to the tape. These peaks are caused by variations in the apparent thickness of the bill because of the engraving of the paper by the intaglio printing process. The detector is a low force device and it is not able to iron out the bill. Figure 4(a) and 4(b) show the waveforms obtained when the phonograph cartridge monitors the deflection of a roller bearing which is spring loaded against the bill. It is possible to exert sufficient force through the roller bearing to iron out the bill and obtain a good indication of thickness. It should be possible to devise signal processing techniques which differentiate between apparent thickness variations and the presence of tape but the most straightforward approach is to use a roller bearing and strong spring forces which iron out the bill. Thus, the engraving of the paper on a bill obviates the advantages of direct contact with the paper with a low tracking force device such as a phonograph cartridge.

The phonograph cartridge serves as an adequate device to sense the deflection of the roller bearing. At present, this approach to tape detection requires multiple devices to scan different areas of the bill. We are investigating an approach based on the same measurement principle, which requires only a single cylinder which will sense the presence of tape anywhere on the bill. This cylinder will be long enough to cover the bill from top to bottom. It will be spring loaded against the bill at each end and each end will have a sensor to detect vertical motion. The output from these two detectors will indicate the presence of tape anywhere on the bill at low speeds and, if the inertia of the cylinder is low enough, it will have an adequate speed of response at twenty bills per second.

3. Detection of Tears, Holes, and Missing Pieces

Measurements of either the optical transmission or reflection characteristics of a bill are quite sensitive to the presence of holes, missing pieces, or tears with folded edges. In the transmission mode, a light source is placed on one side of the bill and a light-sensitive detector is placed on the other side of the bill. The attenuation of the light is a function of the ink pattern on both sides of the bill, but a peak value of less than ten percent of the light incident upon the bill from the light source will pass through the bill and reach the detector. The presence of a defect in the paper will allow additional light to pass through the bill and this will cause a corresponding increase in the output signal from the detector. The

smallest size defect which is detectable depends upon the detection method. In general, a defect which is at least one-tenth of the area of the bill visible to the detector will cause the detector output to rise to a level higher than the peak signal if no defect is present. This signal is sufficient, in theory, to insure detection. In the reflection mode of operation, the light source and the detector are mounted on the same side of the bill. The reflection coefficient depends upon the ink pattern; a peak value of less than ten percent of the light incident upon a bill is reflected to the detector. A mirror reflects a high percentage of the light which strikes it. Therefore if a mirror is used as a reflector, the reflectance mode is very similar to the transmission mode of operation and the signals from the light-sensitive detectors are virtually indistinguishable. An alternative approach is to use a flat-black reflector which has an extremely low reflection coefficient. In this case, the presence of the bill causes an increase in detector output signals and a defect in the bill will cause a reduction in signal strength. This mode of operation is more difficult to implement because it is hard to distinguish between a defect and the black printing on the bill and the system is much more sensitive to stray light and electrical noise.

Either reflection or transmission measurements give equivalent results. A choice between the two depends largely upon which type of measurement is easiest to fit onto a currency handling transport. The transmission method requires access to both sides of the path of the bill through the transport. The reflection method requires access to only one side because the reflector can be part of the transport. For example, if the transport uses a rotating drum to move the bill, the surface of the drum may act as a suitable reflector.

The motion of the bill through a transport system provides a natural scanning of the bill along the direction parallel to the motion. If a narrow strip of the bill, perpendicular to its direction of travel, is examined, the entire bill is scanned. This strip can be examined by one of three ways: optically focusing the desired image onto a single detector, 2) mounting a line of small detectors to cover the desired area, or 3) rapidly scanning a small detector across the desired area. The first approach has the advantage of using only a single light sensitive source and light-sensitive detector. It is advantageous to need only one light-sensitive detector because the sensitivity of detectors is variable from unit to unit; the use of multiple detectors requires some type of gain equilization to obtain

accurate measurement. The smallest perceivable defect, however, is a function of the area of the bill seen by the detector. The use of a single stationary detector requires that the detector see a relatively large area and it will be more difficult to detect small defects. The choice between the second and third approach is largely that between using multiple detectors, which must be calibrated, and fabricating a suitable scanning mechanism. We have chosen to use the multiple detector approach to demonstrate a means of detecting tears, holes, and missing pieces.

The signals from the multiple detectors must be combined in order to obtain a single indication of whether or not a bill is structurally intact. Consider the response of the detectors as a bill moves past them. Initially, until the bill reaches the detection area, the light beam to each detector is not interrupted and each detector output signal is at a high level. When the front edge of the bill interrupts the beams, the output level at each detector falls to less than ten percent of its former value. If the bill has no structural defects, all the output levels will remain at a low value until the trailing edge of the bill passes the detection area. Tears, holes, or missing pieces will allow more light to pass through the bill and this will cause a momentary increase in the output level of at least one of the detectors.

Each detector output can be thought of as a bi-level signal; the output is low when the bill interrupts the path of the light beam from the light source to the detector and it is high if the bill does not interrupt the beam. The combination of the outputs of multiple detectors at any instant is described by one of the following cases: 1) all the outputs are high, 2) all the outputs are low, or 3) some of the outputs are high and some are low. The first case describes the case where no bill is being scanned. The second case describes the case where the portion of the bill being scanned is structurally intact. The third case is the case where the detectors indicate the presence of a defect in the portion of the bill being scanned.

Figure 5 is a block diagram of the electronic circuitry which combines the signals from the multiple detectors into a single indication of the structural integrity of a bill. The motion of the bill past the light-sensitive detectors causes a continuously varying voltage to appear at the output of each detector. The instantaneous value of each output is one input to one of the voltage comparators. The other input of the comparator is a reference voltage which acts as a threshold value. If the output of a detector

7

exceeds the threshold value, the signal at the output of that comparator is high. If the output of the detector is less than the threshold value, the output of that comparator is low. Thus, the comparator acts to convert the analog signal present at the output of each light-sensitive detector into a bi-level signal. The comparator signals form the inputs to two digital circuits which perform the logical AND and the logical OR functions respectively. The output of the logical AND circuit is high if and only if all of its inputs are high. Thus, a low signal is obtained whenever the bill interrupts the beam to any detector. The low signal indicates that a bill is present and the duration of the low signal is a measure of bill length for a bill moving at a constant known speed. The output of the logical OR circuit is low if and only if all of its inputs are low. A high output from the logical OR circuit occurs whenever any input is high. This happens when no bill is present at the detectors or when the bill present does not sufficiently cover one of the detectors because of a fold, tear, hole or missing piece. The three possible states of the combination of the outputs of the two logic circuits are listed in Table 1.

Table 1

Condition	OR output	AND output
No bill present	High	High
No defect being scanned in bill present	Low	Low
Defect being scanned in bill present	High	Low

The two signals are the input to a circuit which looks for the third condition and triggers an indicator whenever the output of the OR circuit is high at the same time that the output of the AND circuit is low. This function can be obtained many ways. It is the natural function of an EXCLUSIVE OR gate and it can also be obtained by inverting the output of the logical AND and feeding this signal and the output of the logical OR circuit into a simple NAND gate. The indicator control circuitry also compares the time duration of the low level state of the output of the logical OR circuit with that expected for a fit bill moving through the transport. If the low level state does not exist for the correct length of time, the circuit triggers the indicator. The trigger signal to the indicator may be

used to route the bill to the appropriate output pocket of the transport.

4. Verification of Denomination

Entire notes have been scanned with a document scanner which moves a small spot of light over a stationary photographic negative of the document. This instrument converts the reflectance of each point on the bill into a voltage level and records the magnitude of the voltage at each point on the bill onto magnetic tape in a form which is suitable for entry into a computer. We have programmed the computer to convert the recorded voltage magnitude into gray levels by associating heavy printing characters with low reflectance values and progressively lighter printing characters with progressively higher reflectance values. The computer printout from this program is a crude picture of the bill.

The front and back sides of a one, five, ten and twenty dollar bill have been scanned. The computer printout for these scans is reproduced in Figures 6 through 9. The document scanner digitized each scan into 160 points along the long dimension of the bill and 64 points across the short dimension of the bill, recording 10,240 points for each side of each bill. This is equivalent to a spot diameter of approximately 1 mm. Each recorded point was a number between 0 and 15, representing sixteen possible reflectance values. The computer program restricts the possible number of gray levels on the printout to seven because that was the best character set that we found. The correlation between the sixteen voltage levels and the seven gray levels on the printout was chosen to optimize the visual quality of the pictures in Figures 6 through 9. The picture quality clearly demonstrates that the electrical signals generated by the scanner contain the desired information on the denomination of a bill.

The denomination of a bill can be verified by machine by making a point by point comparison between measured values of reflectance and those expected for a bill of a given denomination. One powerful method of doing this is the masking technique used in the optical character recognition and pattern recognition fields. We have simulated on the computer a negative mask which is placed between a bill and a light-sensitive detector. The negative mask allows light to pass through it only at those points

where the image of a bill of the correct denomination has low reflectance values and it prevents the passage of light at those points where the image of a bill of the correct denomination has high reflectance values. If the mask is the correct size, and if the image of the bill is well registered on the mask, very little light will reach the detector when the mask is the negative of the bill being examined. A considerable amount of light will shine through that mask from the image of a bill of any other denomination. Thus, the denomination of a bill can be determined by imaging the bill through negative masks of each possible denomination and comparing the detector outputs to ascertain the best match. The computer printouts obtained from the simulation program are reproduced in Figures 10 through 25. Since only one scan of each side of each denomination was recorded, the image of a bill through a negative mask of itself is, by definition, completely blank. This is the case in Figures 10(a), 12(a), 14(b), 16(b), 19(a), 21(a), 23(b) and 25(b). The rest of the figures show the result when a bill is image d through a negative msk of a bill of a different denomination. The light printing character indicates those points where light reaches the detector. A summation of the number of these characters indicates the magnitude of the signal output that would be obtained from the detector. These figures indicate that the denomination of a bill is clearly identifiable under ideal conditions. In fact, only a few points would need to be checked to verify denomination and the rest of the information could be ignored.

When conditions are less than ideal, the results are not as clear. A bill in motion through a transport will not register perfectly with the mask and if the bill is not in perfect condition the image of the bill will not correspond exactly with its mask. For example, white paint on a bill may give a high reflectance value to a region which should have a low reflectance value and this light will pass through the mask of that denomination. In this case, no detector will have a null output and it will be more difficult to ascertain denomination. Misregistration of the image of the bill on the mask will also permit light to pass through the mask of the correct denomination and, again, no detector will have a null output. If enough light reaches the detector because of these problems it is not possible to verify the denomination of a bill.

Two different methods of implementing the masking technique are under consideration. One approach is entirely optical, where multiple images of a bill are formed. Each image is shown through a mask onto a light-sensitive

10

detector. The masks are each a photographic negative of one
of the different denomination bills. Additional masks of
each denomination are provided for each possible
misregistration position. As the bill moves through the
transport, its image will register on one of the masks of
the corresponding denomination and that detector will, at
that instant, have a low output signal. Continuous
comparison of the detector outputs will indicate which mask
best matches the bill and thus the denomination of the bill
is identified. This approach is particularly attractive if
it is necessary to attain high resolution, i.e., if it takes
many points to determine denomination. It requires,
however, the forming of multiple images of the bill. The
number of images and masks required depends upon the number
of denominations which must be verified and upon the number
of misregistration positions which must be covered. For
example, if there are four different denominations and three
different registration positions for each denomination,
twelve images of the bill must be formed. In addition, this
approach would probably require a clear view of the entire
bill. This may be difficult to obtain on some transport
systems.

The second approach is to immediately convert the image
of the bill into electrical signals and to then mask these
signals electrically. The electrical signals are loaded
into an array where the position of each signal in the array
corresponds to the reflectance value of a point on the bill.
The denomination of a bill is determined by circuits which
compare the signals at each position of the array with that
expected for a bill of a given denomination and identifying
which comparison yields the highest correlation.
Misregistration can be handled by shifting the position of
the signals in the array. This approach does not require
multiple images and, in fact, does not require a clear view
of the entire bill. If high resolution is required,
however, the size and complexity of the circuitry tends to
become unmanageable. A choice between these two approaches
depends upon the number and size of the points necessary to
verify the denomination of a bill, the effect of
misregistration on the techniques, and the availability of
an appropriate area in the transport mechanism to mount the
necessary hardware.

5. Plans For Future Work

1. Develop a method of verifying the denomination of a bill
    while it is in motion through a transport system.
    Attention will be given to the signal degradation due to

misregistration of the bill in the transport mechanism.
Masks which delineate various portions of the bill will
be investigated and both electronic and optical methods
of imaging the bill through a mask will be considered.

2.   Integrate the optical methods of detecting tears, holes,
     and missing pieces with the thickness measurement to
     obtain electrical signals which specifically indicate
     the presence of tape, tears, holes, missing pieces or
     folds.

6.   Bibliography

(1) Stokesberry, D. P. and Philmon, I., Evaluation of Methods of
    Automatically Determining the Fitness of Currency, NBS Report
    NBSIR 73-143, February 1, 1973.
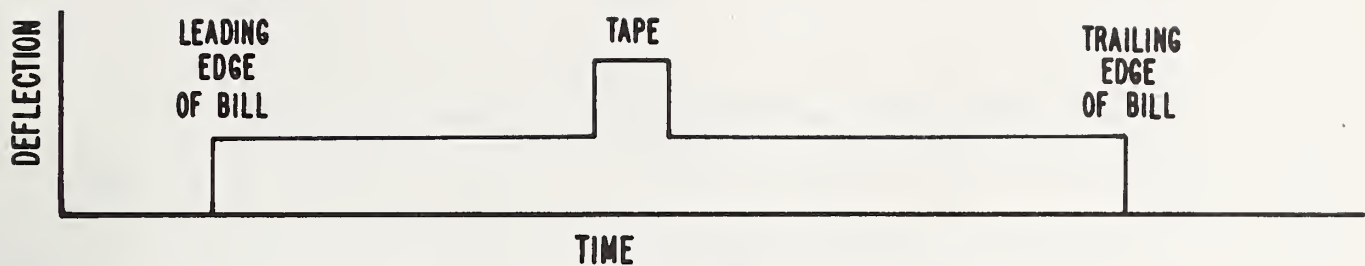
(a) DEFLECTION OF THE SENSOR BY THE BILL
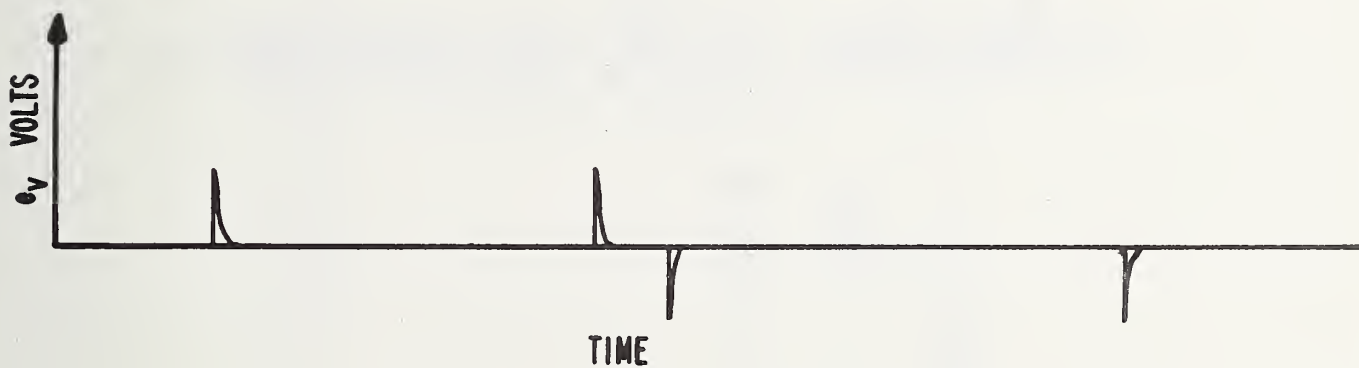
(b) OUTPUT SIGNAL ,e_V , FROM THE PHONOGRAPH CARTRIDGE
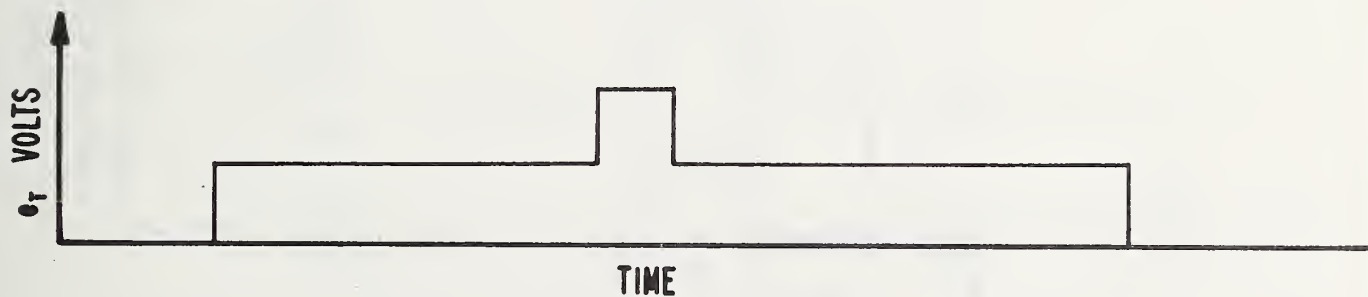
(c) SIGNAL e_T OBTAINED BY INTEGRATING OUTPUT SIGNAL e_V

Figure 1. Idealized response obtained when a bill with tape on it is scanned by a phonograph cartridge.
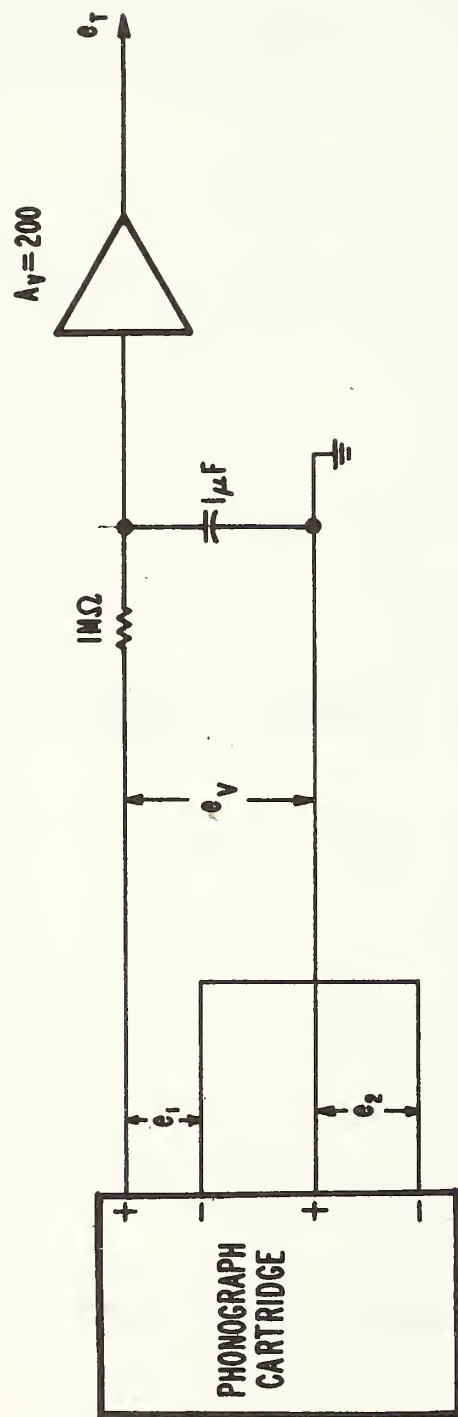
Figure (2) Schematic diagram of the circuitry used to measure the thickness of a bill with a phonograph cartridge.
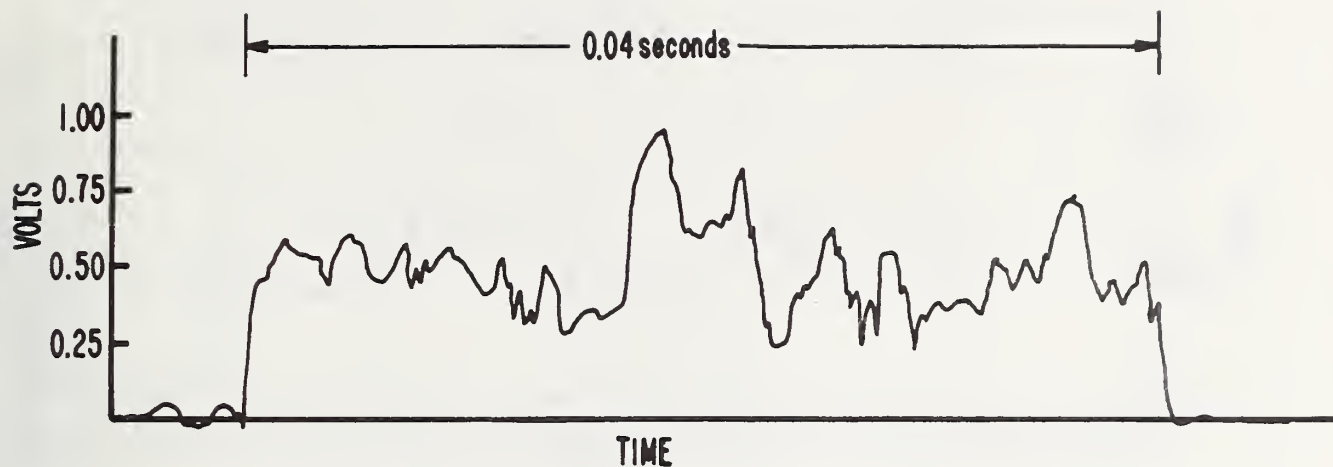
(a) SIGNAL OBTAINED FROM A TAPED BILL WITH THE DETECTOR
DIRECTLY CONTACTING THE BILL
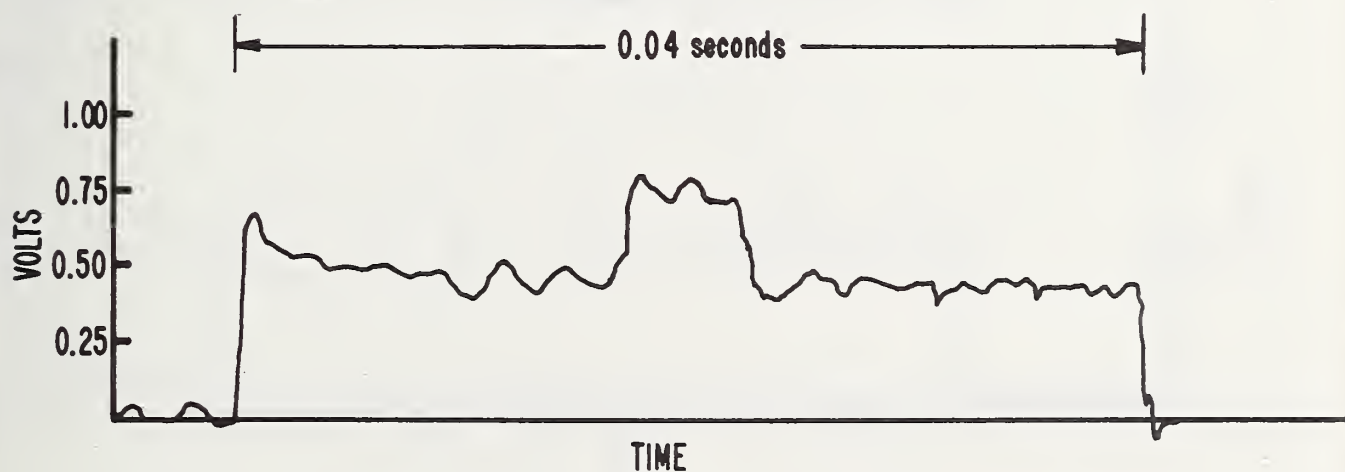
(b) SIGNAL OBTAINED FROM A TAPED PIECE OF BOND PAPER WITH
DETECTOR DIRECTLY CONTACTING THE PAPER

Figure 3.   Integrated output signal from a phonograph cartridge
directly contacting the bill.
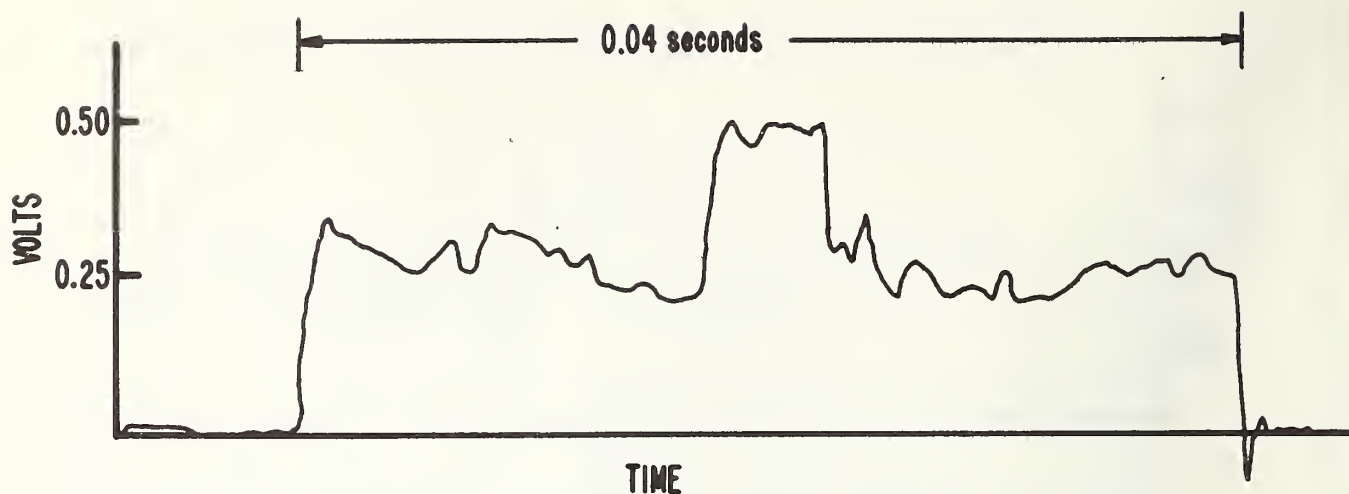
(a) SIGNAL OBTAINED FROM A TAPED PIECE OF BOND PAPER WITH THE DETECTOR CONTACTING THE ROLLER BEARING
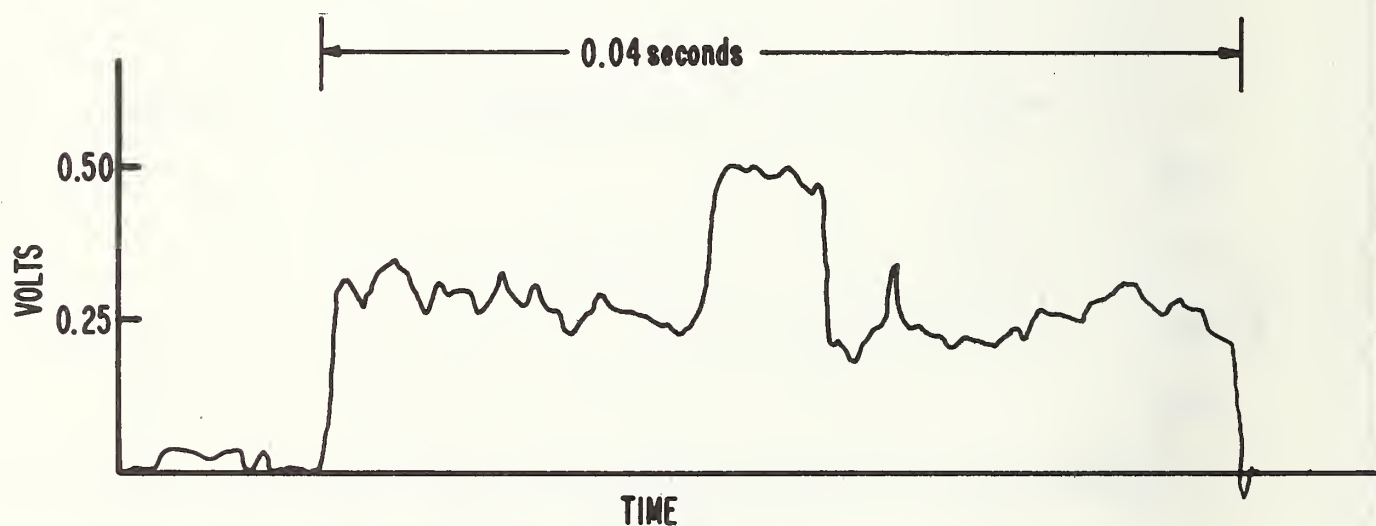
(b) SIGNAL OBTAINED FROM A TAPED BILL WITH THE DETECTOR CONTACTING THE ROLLER BEARING

Figure 4. Integrated output signal from a phonograph cartridge detector mounted on a spring loaded roller bearing.
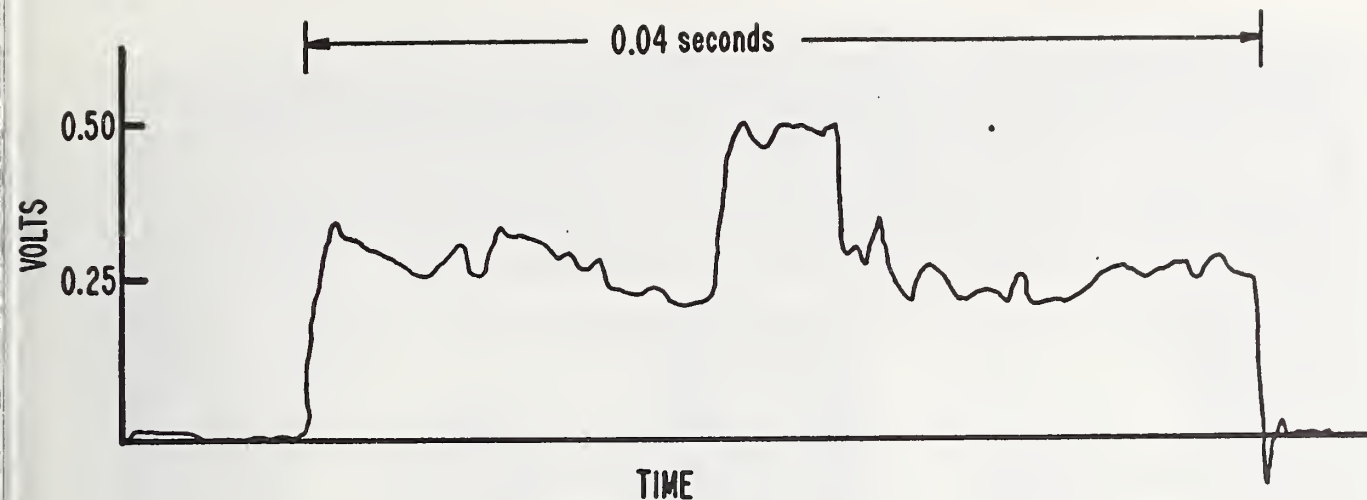
(a) SIGNAL OBTAINED FROM A TAPED PIECE OF BOND PAPER WITH THE DETECTOR CONTACTING THE ROLLER BEARING
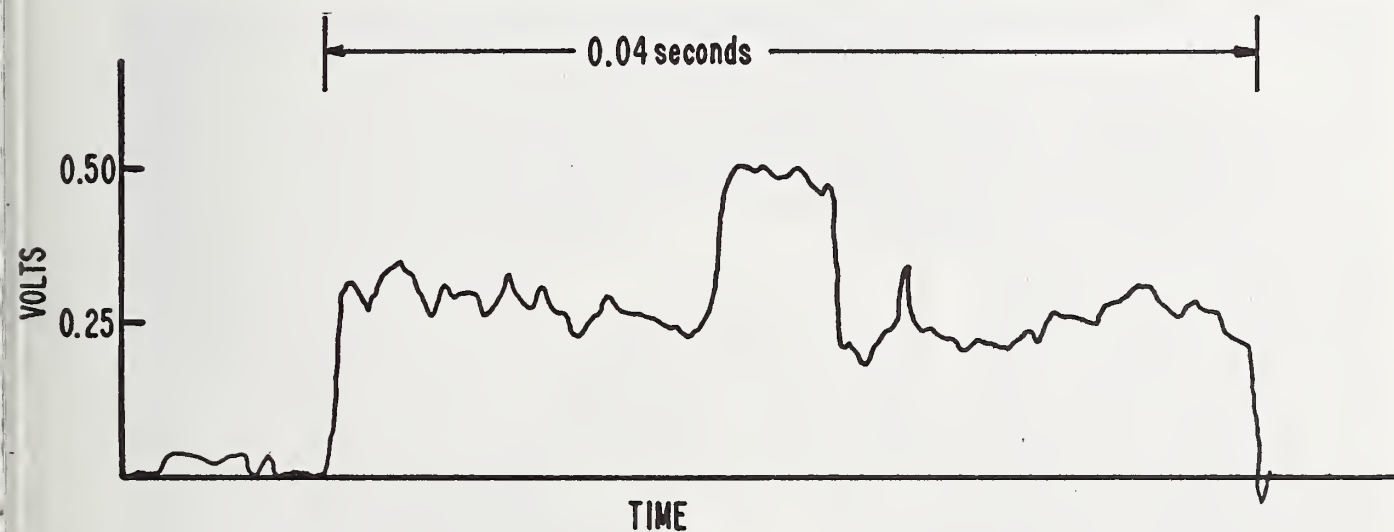
(b) SIGNAL OBTAINED FROM A TAPED BILL WITH THE DETECTOR CONTACTING THE ROLLER BEARING

re 4. Integrated output signal from a phonograph cartridge detector mounted on a spring loaded coller bearing.
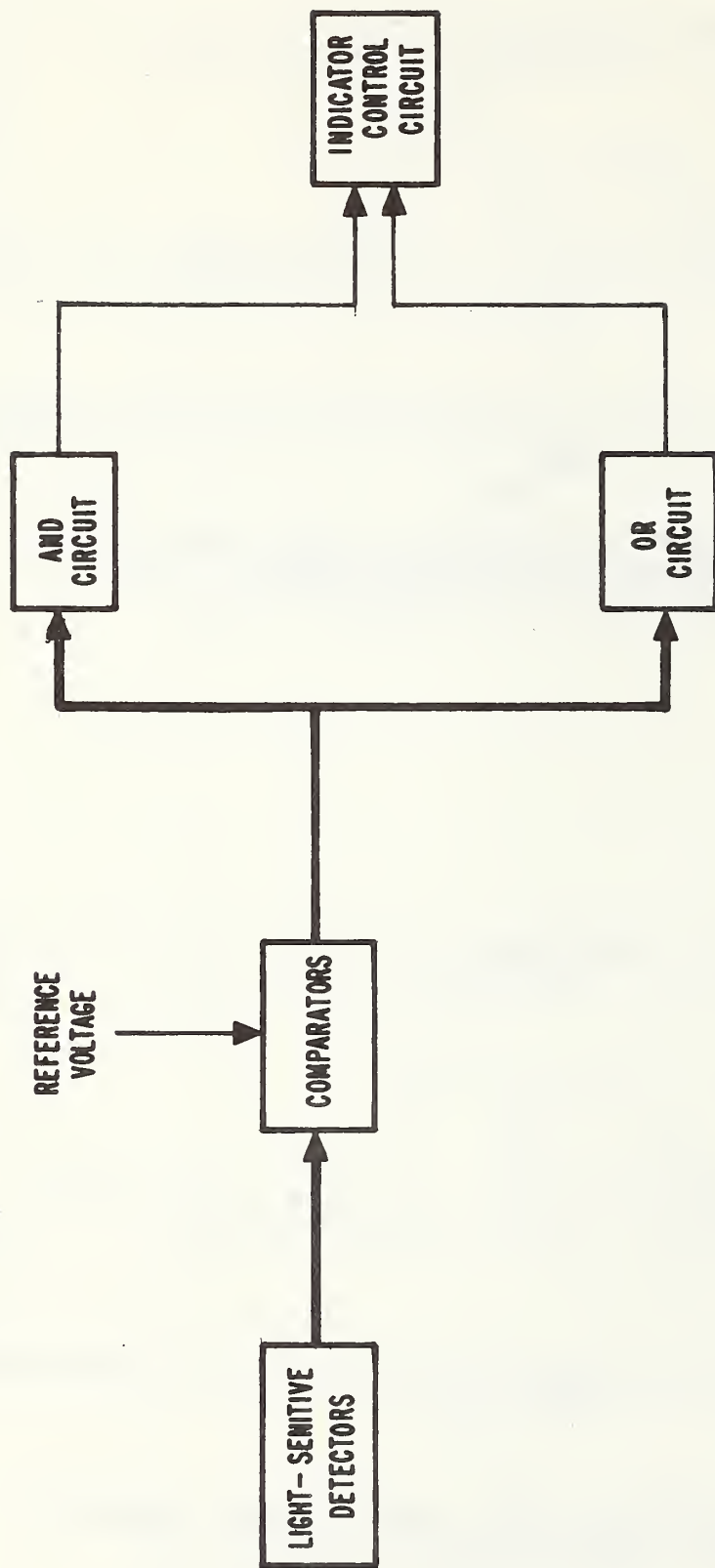
Figure 5. Block diagram of the electronic circuitry to combine the signals from the multiple detectors into a single indication of the structural integrity of a bill.
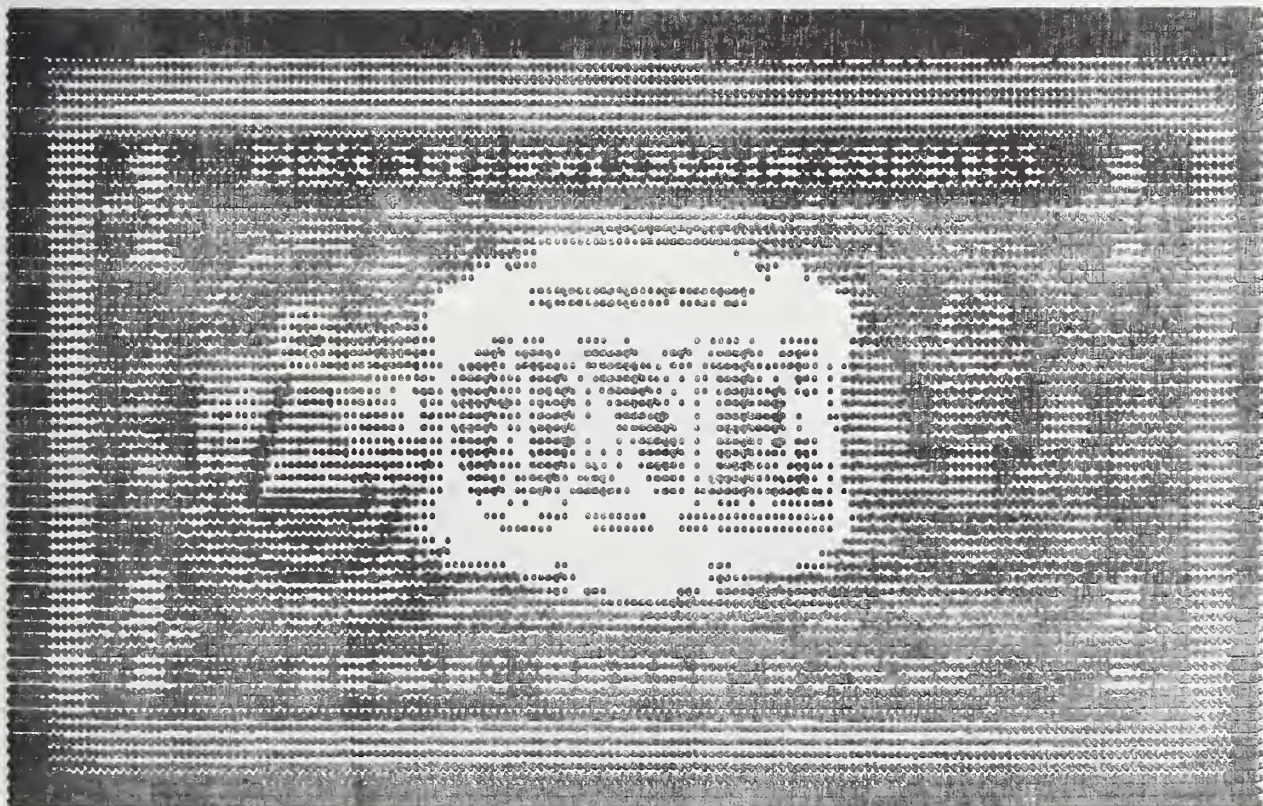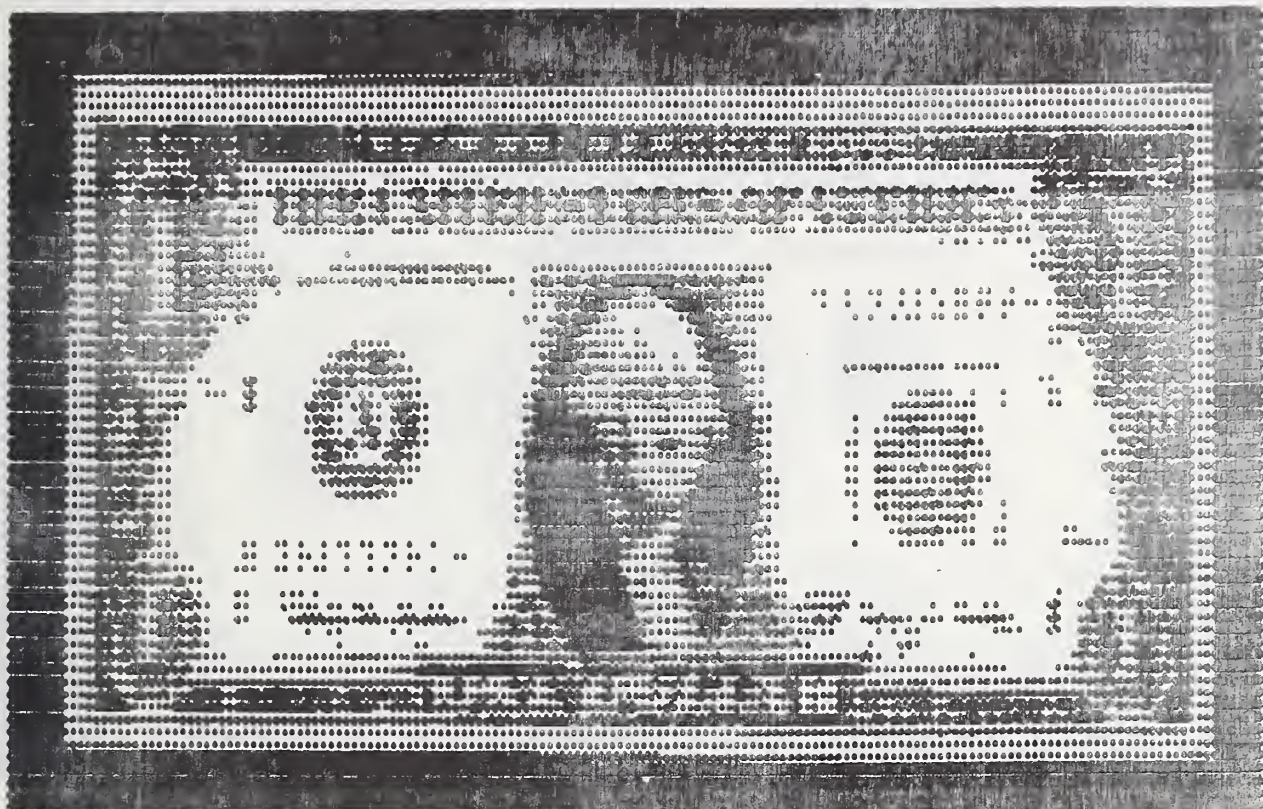
Figure 6. Computer printout of scans of the front and back of a one dollar bill.
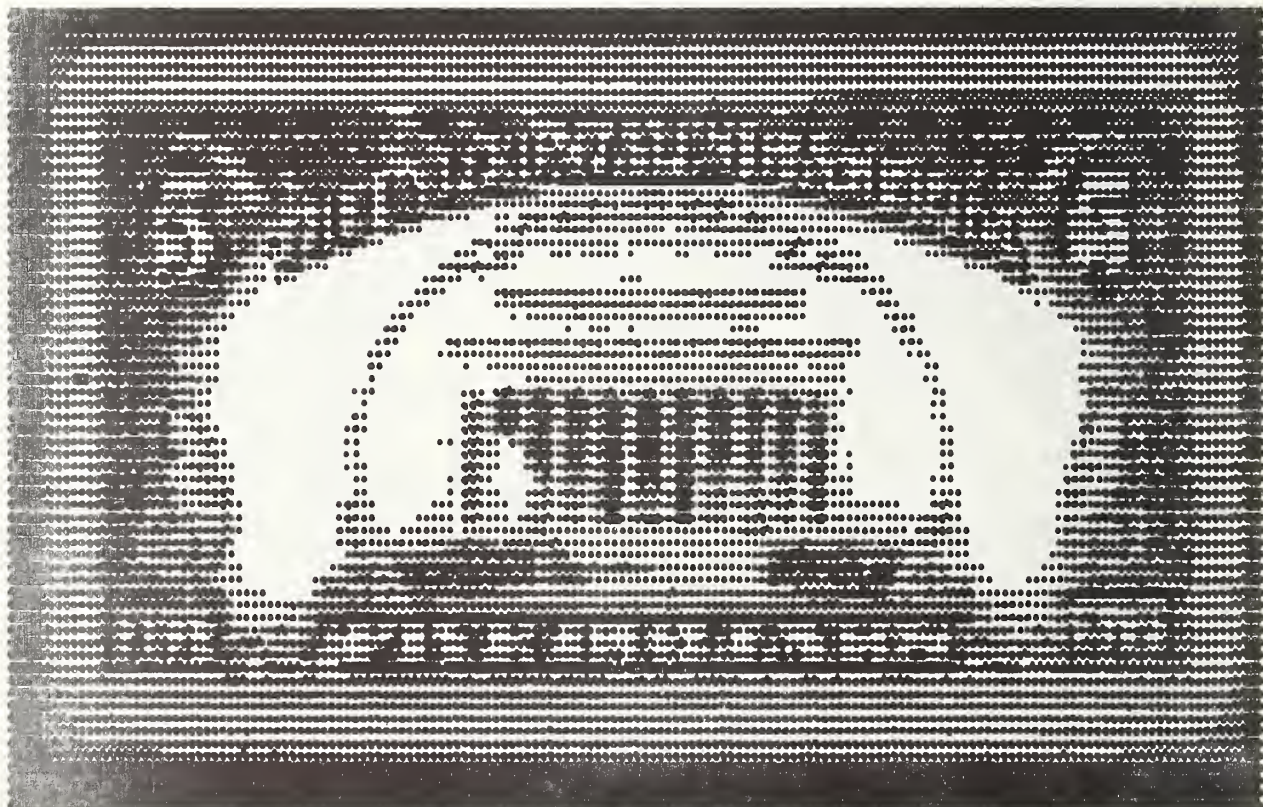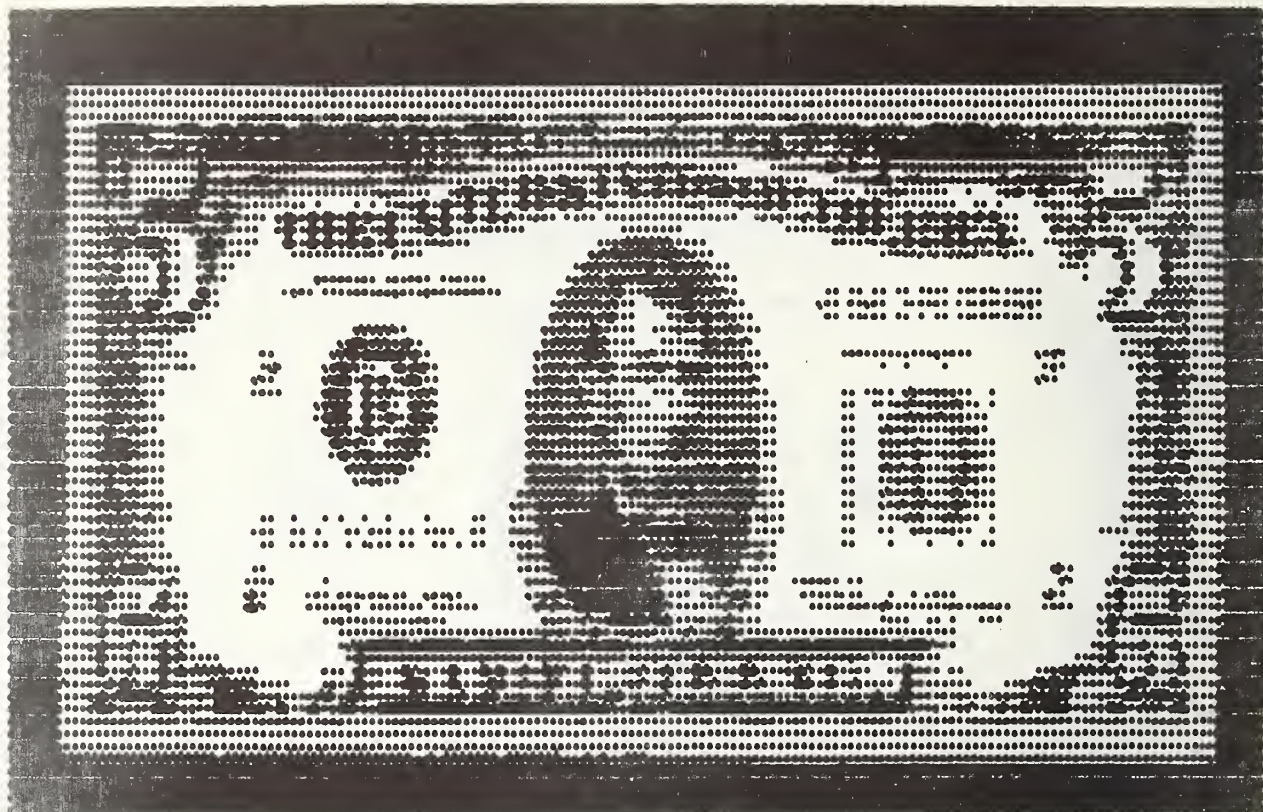
Figure 7. Computer printout of the front and back sides of a five dollar bill.
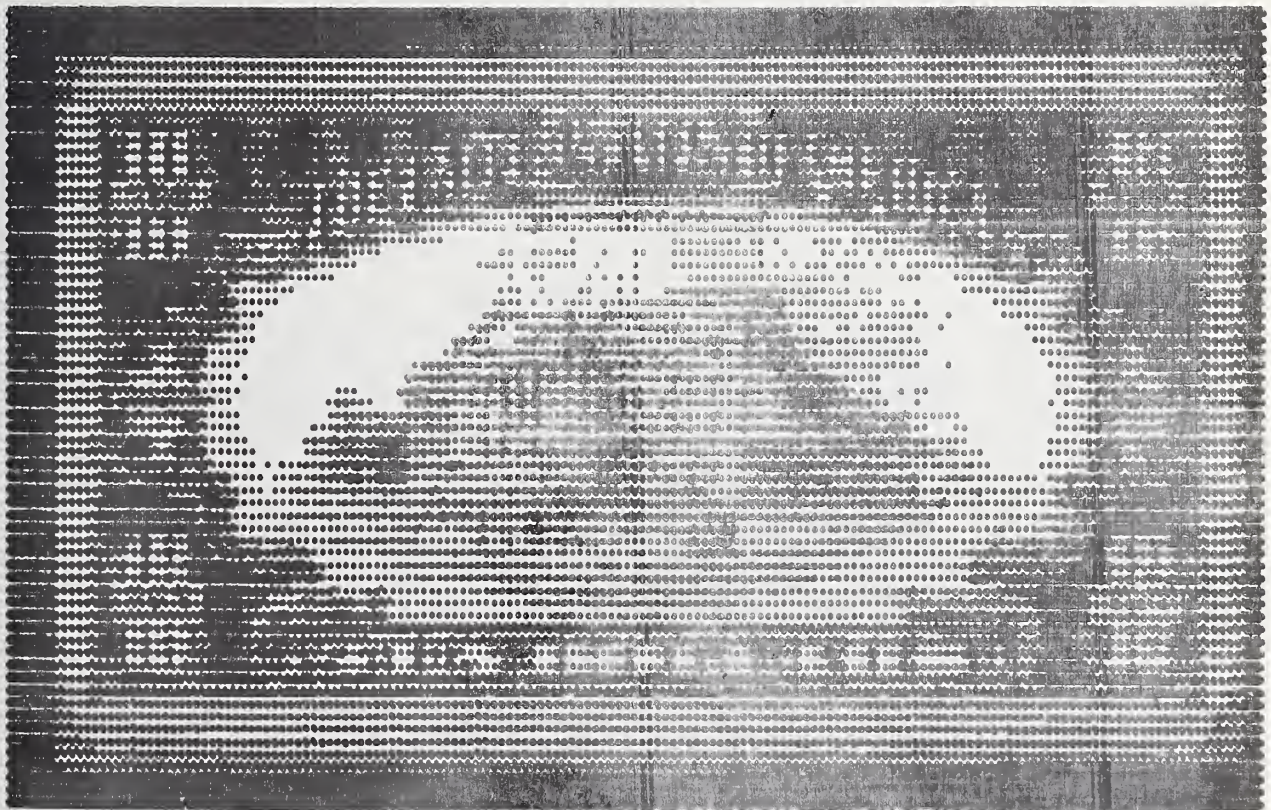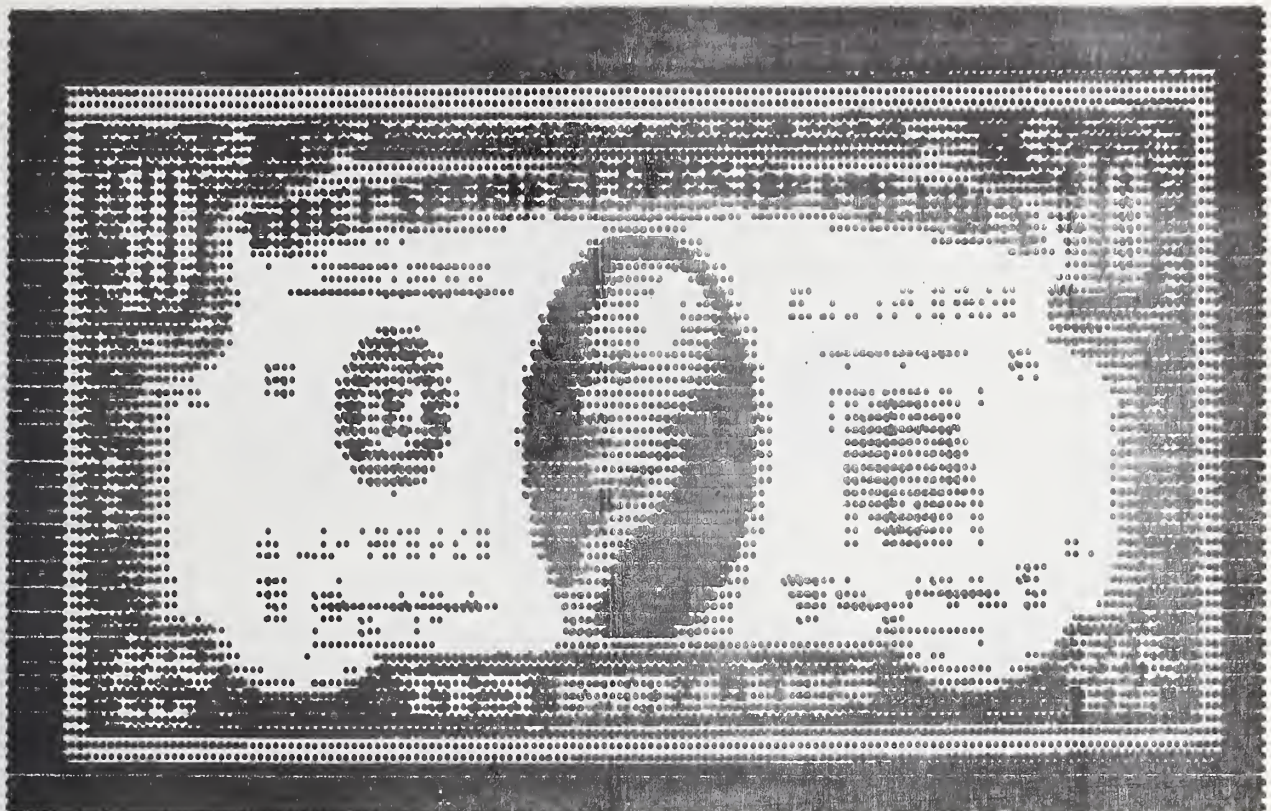
Figure 8. Computer printout of the front and back sides of a ten dollar bill.
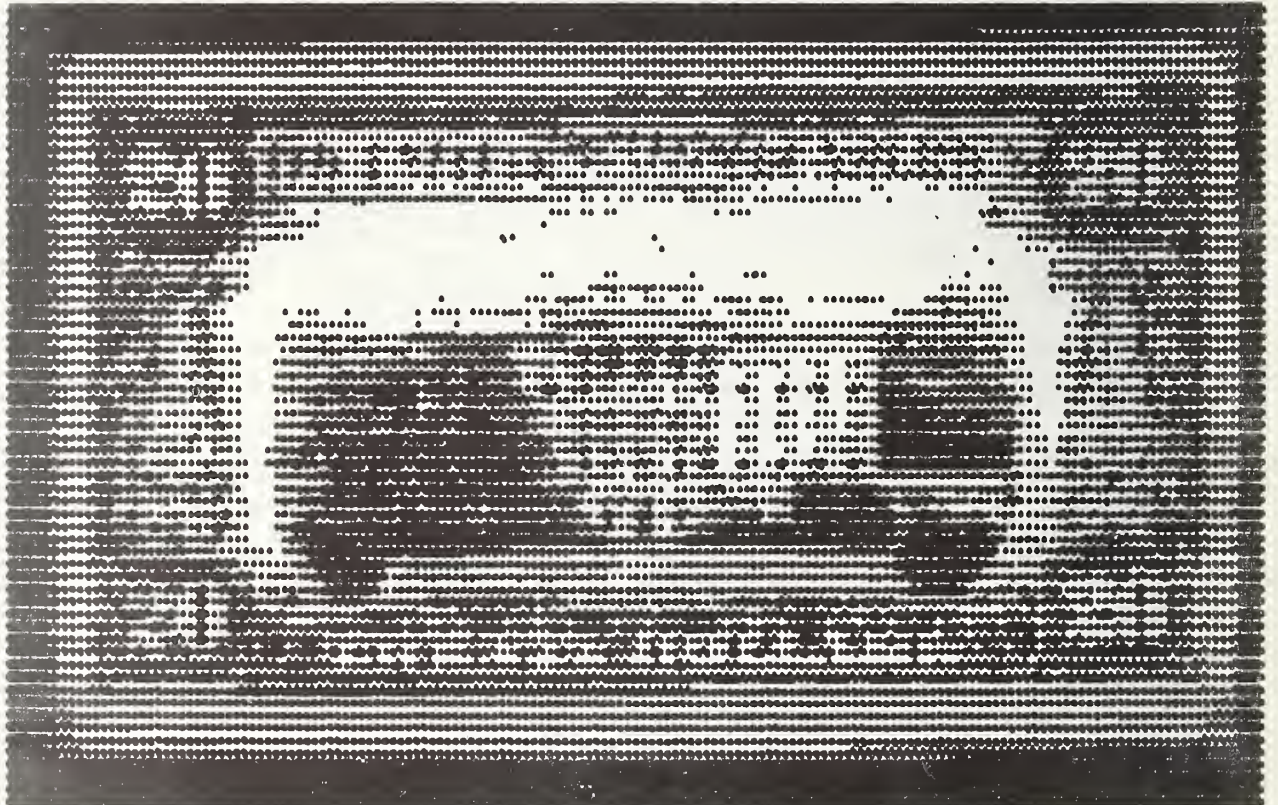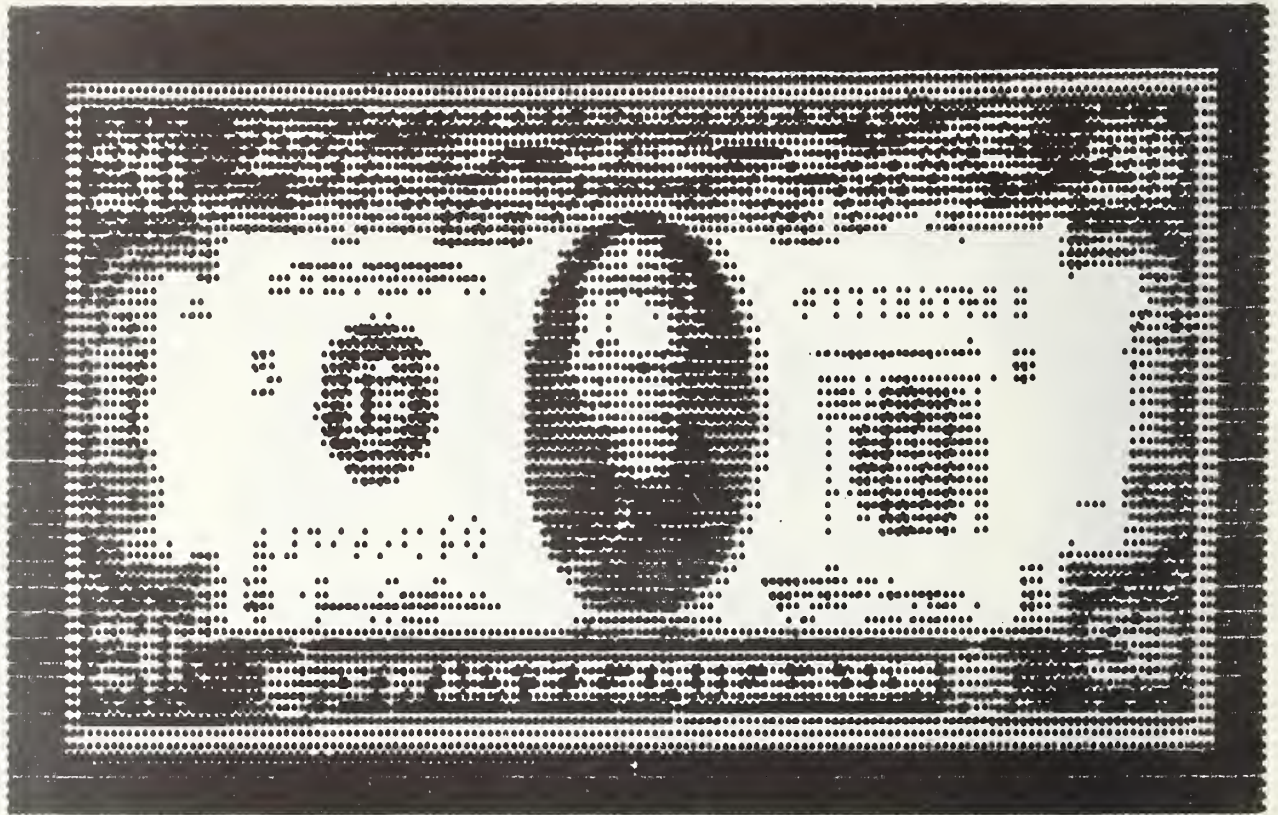
Figure 9. Computer printout of the front and back sides of a twenty dollar bill.

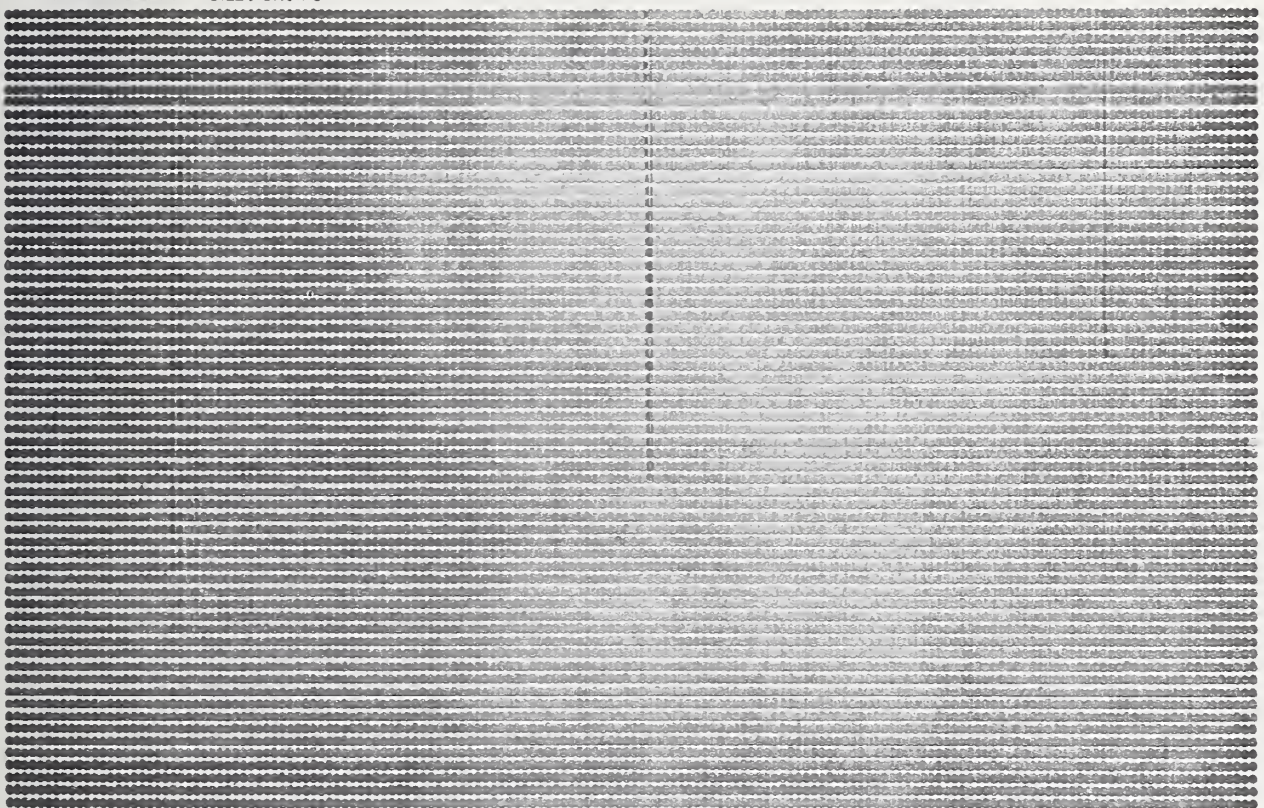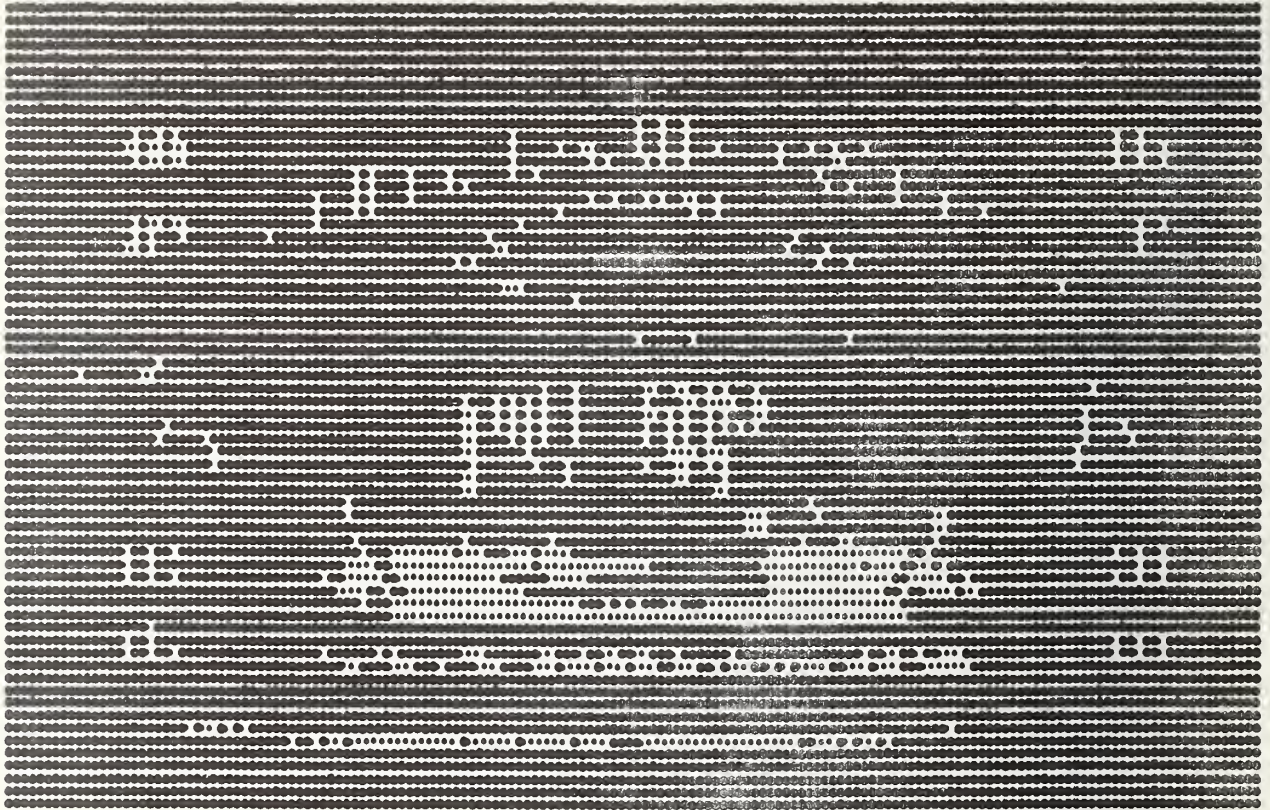(A) MASK: ONE   BILL: ONE
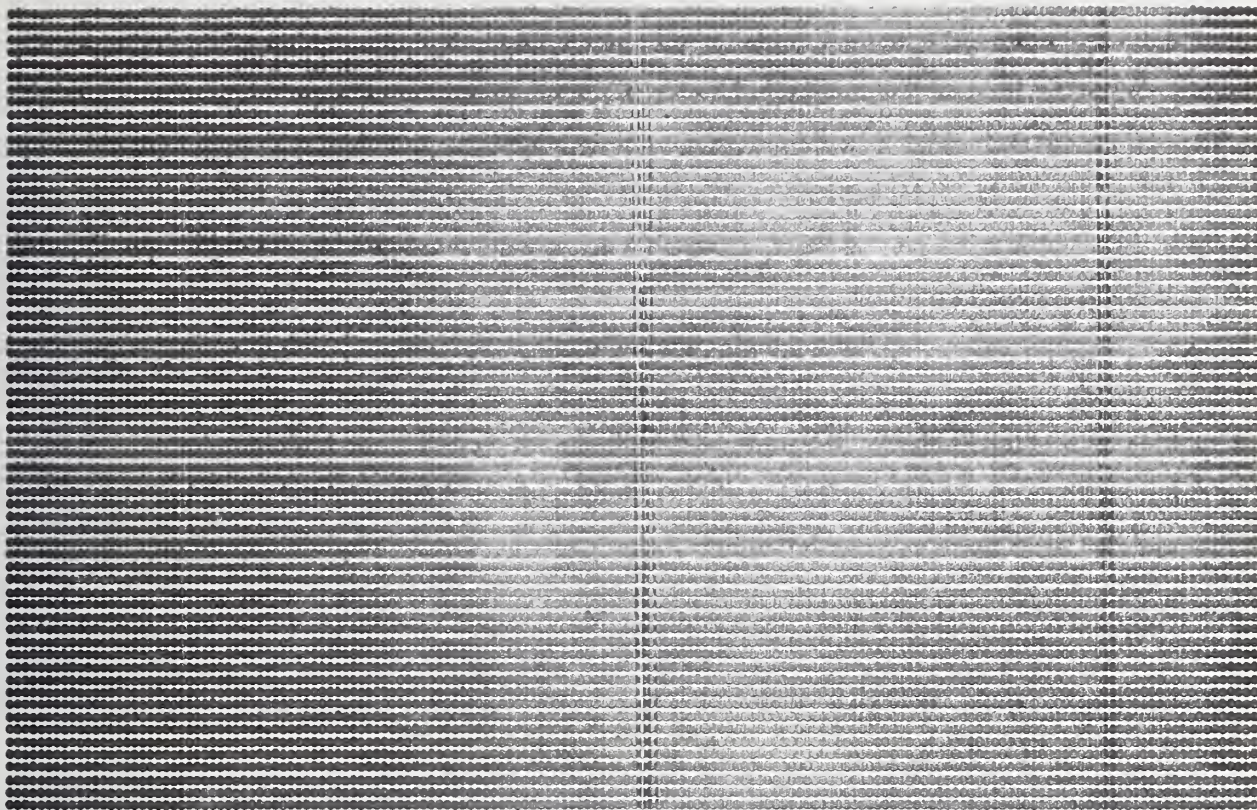
(B) MASK: ONE   BILL: FIVE
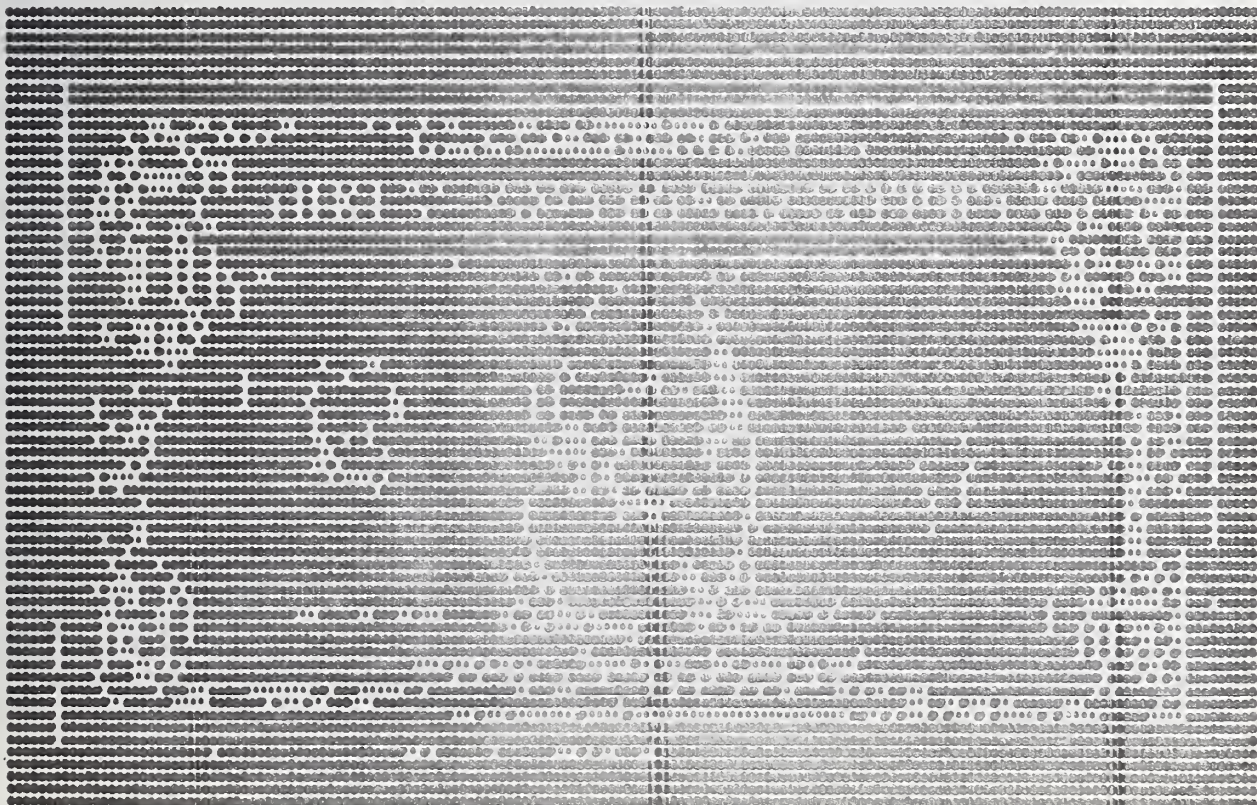
Figure 10. Computer printout showing where light from the images of the front sides
of a one and a five dollar bill shine through a negative mask of the front
side of a one dollar bill.

(A) MASK: ONE   BILL: TEN
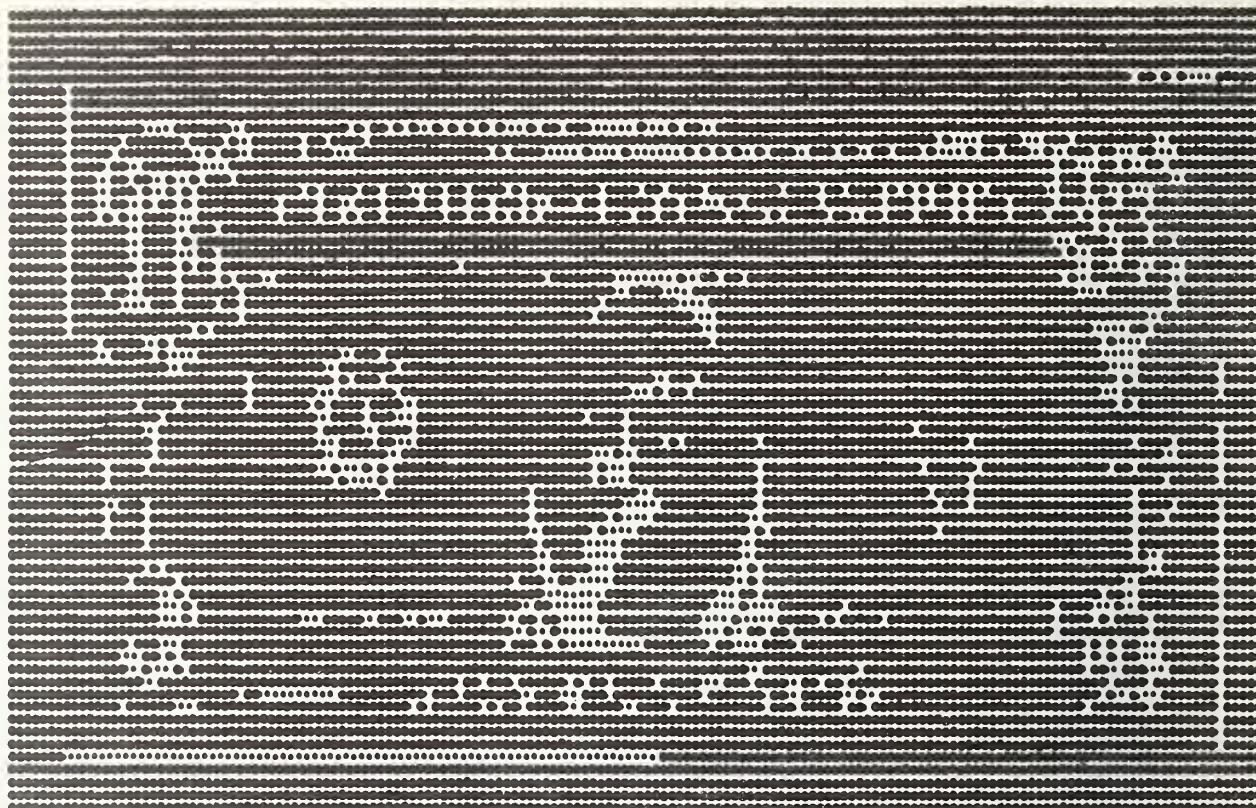
(B) MASK: ONE   BILL: TWENTY
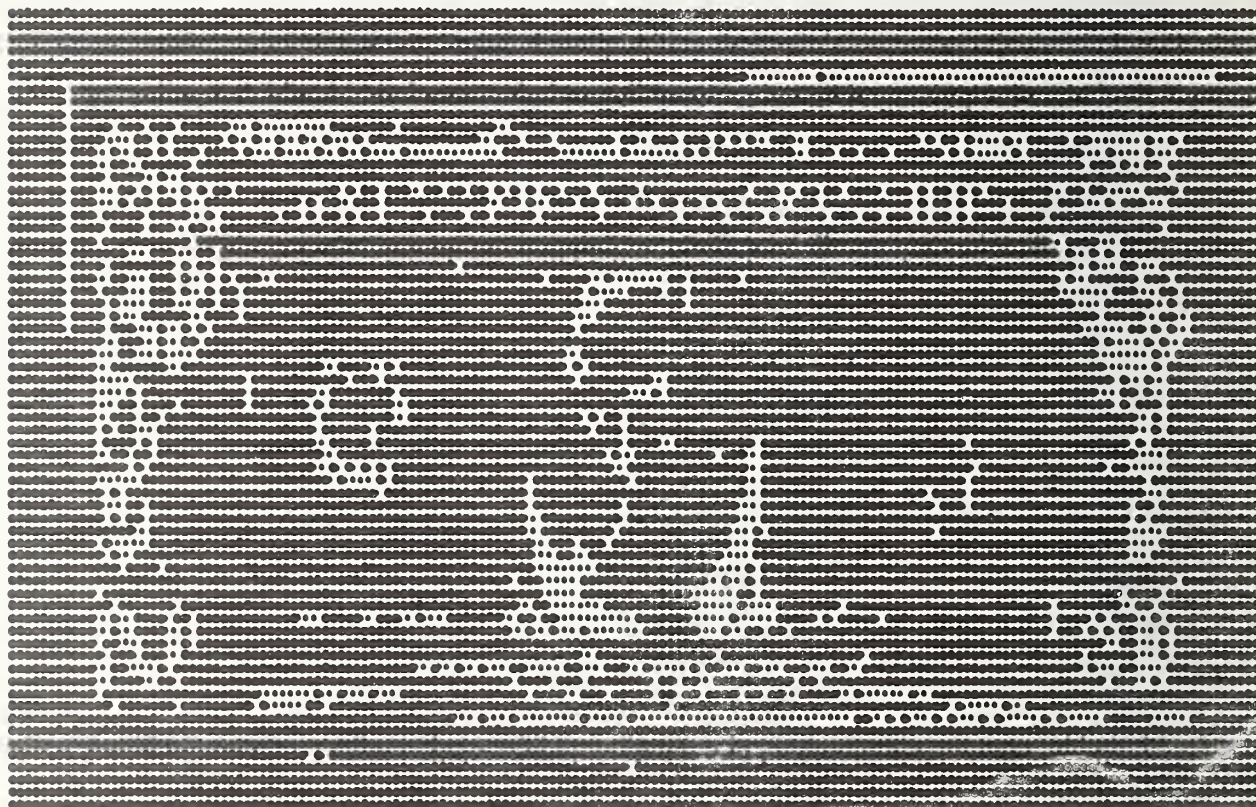
Figure 11. Computer printout showing where light from the images of the front sides
of a ten and twenty dollar bill shine through a negative mask of the front
side of a one dollar bill.

(A) MASK: BACK 1   BILL: BACK 1
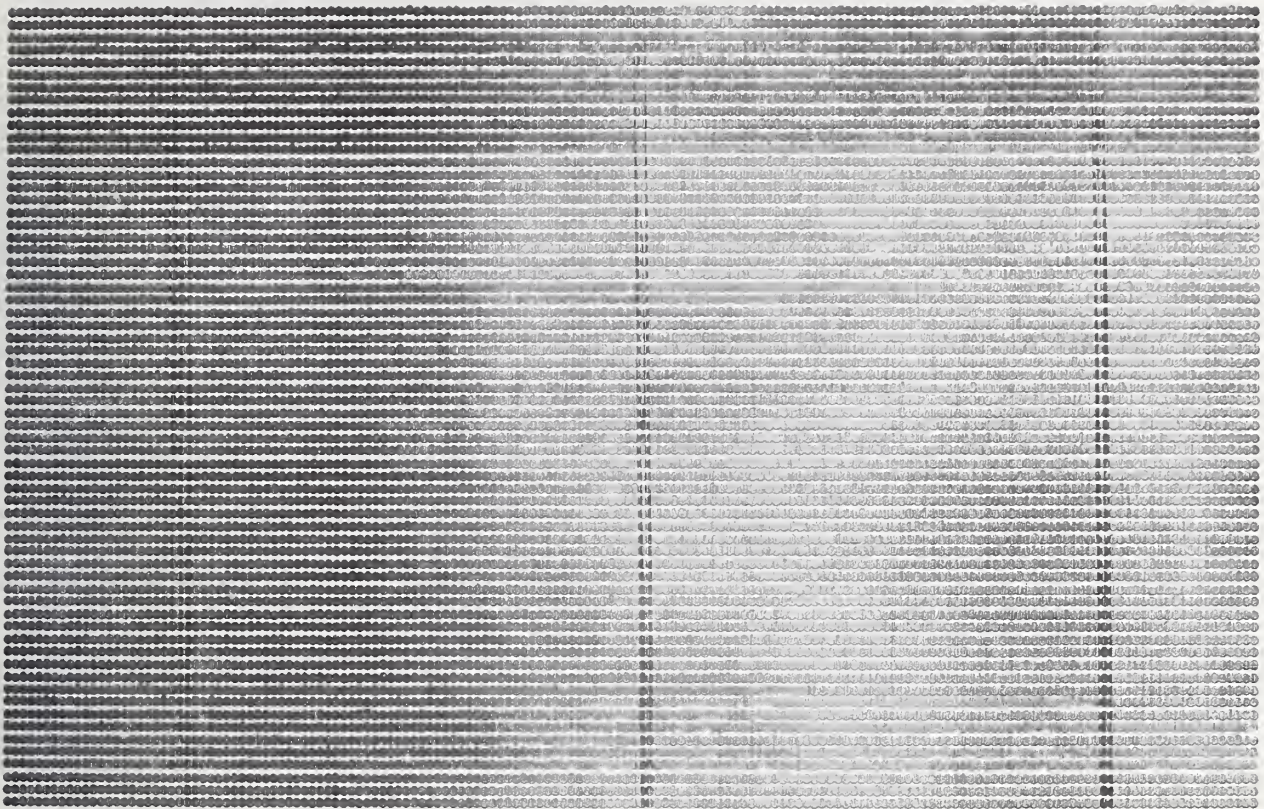
(B) MASK: BACK 1   BILL: BACK 5
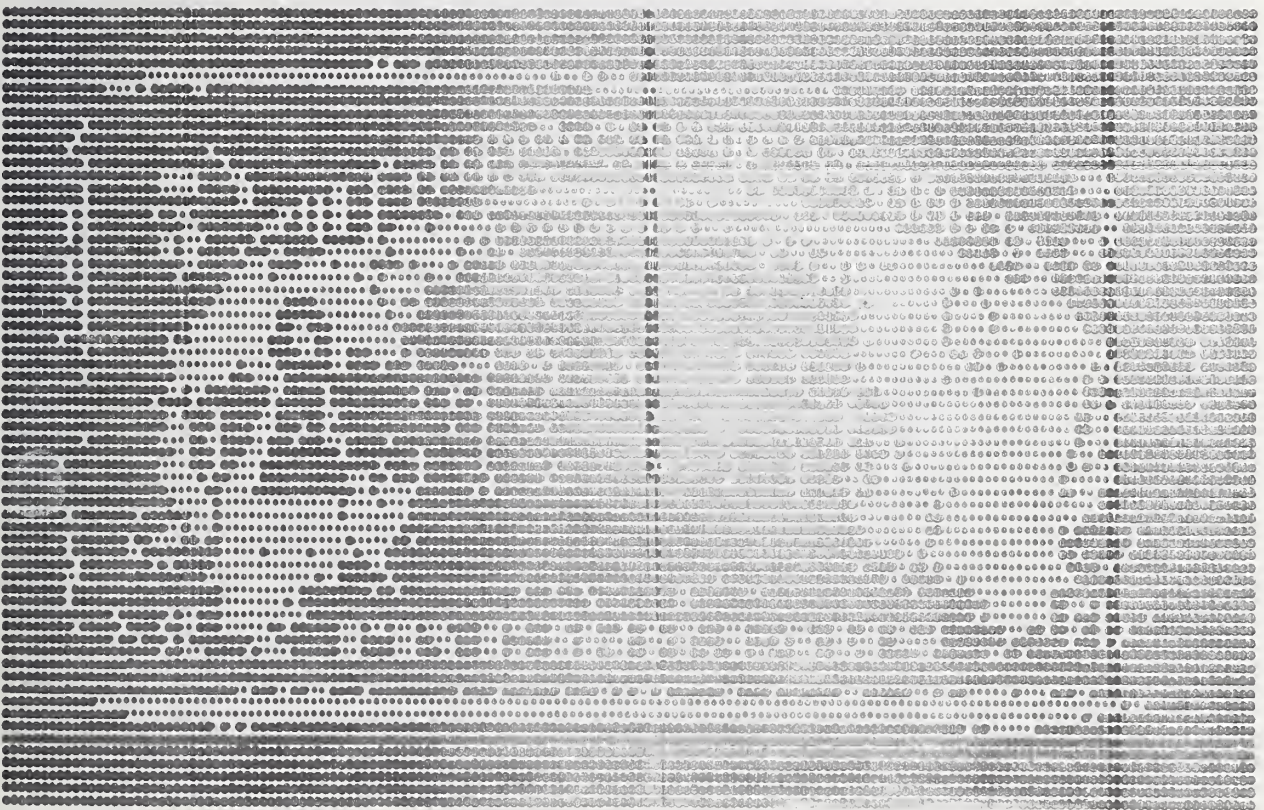
Figure 12. Computer printout showing where light from the images of the back sides of a one and a five dollar bill shine through a negative mask of the back side of a one dollar bill.

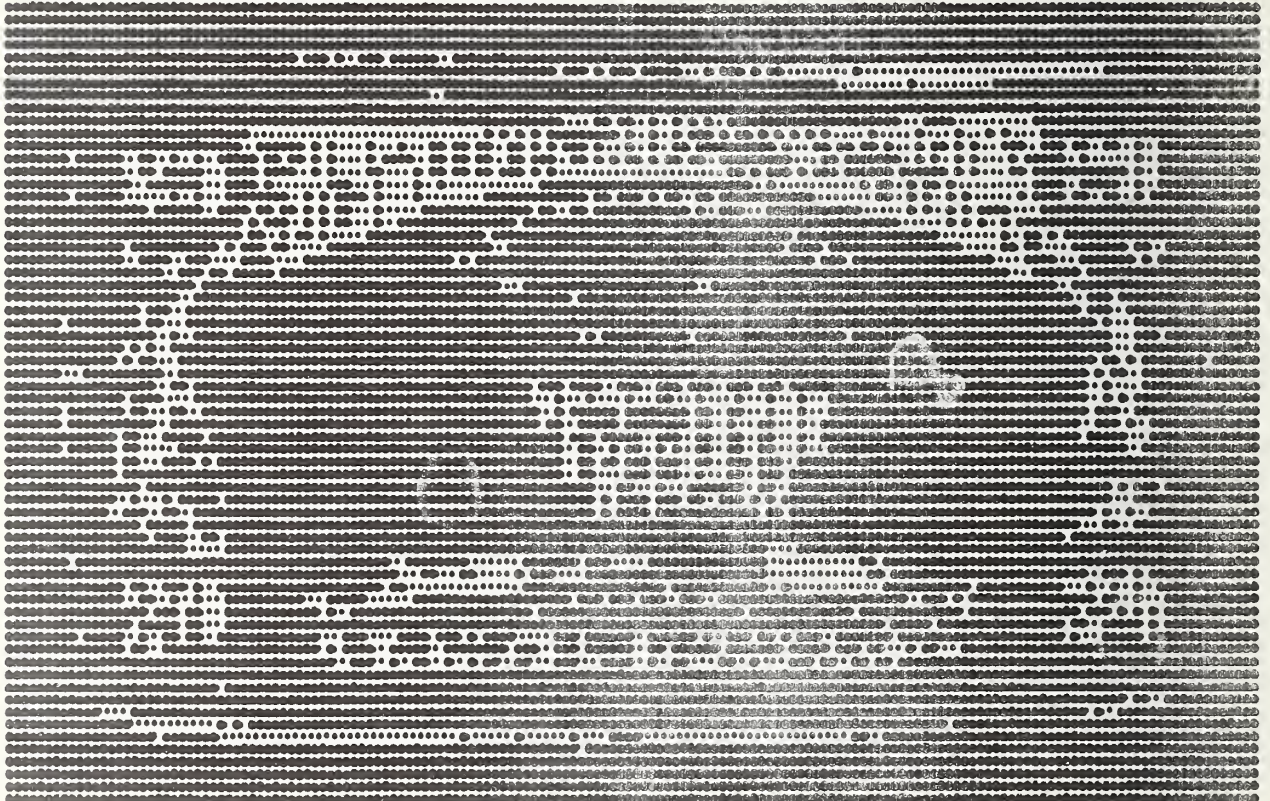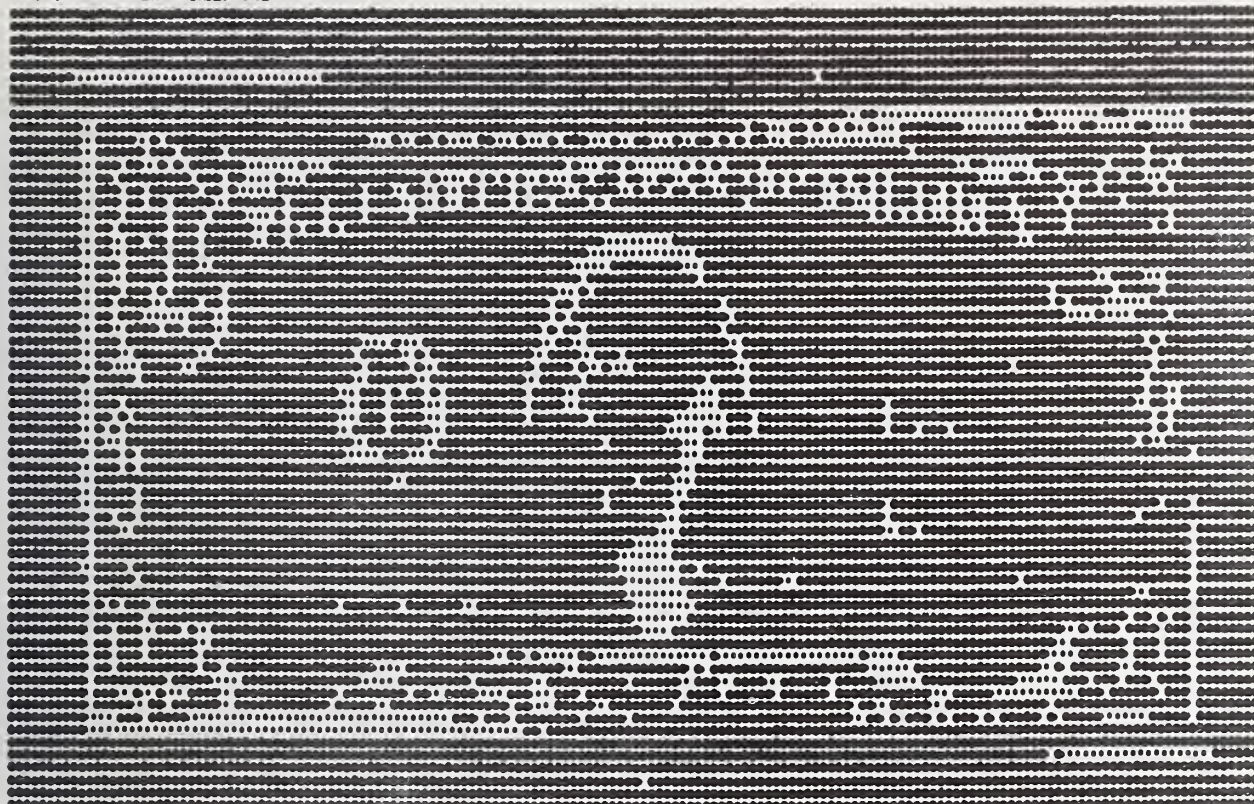(A) MASK: BACK 1   BILL: BACK 10

(B) MASK: BACK 1   BILL: BACK 20
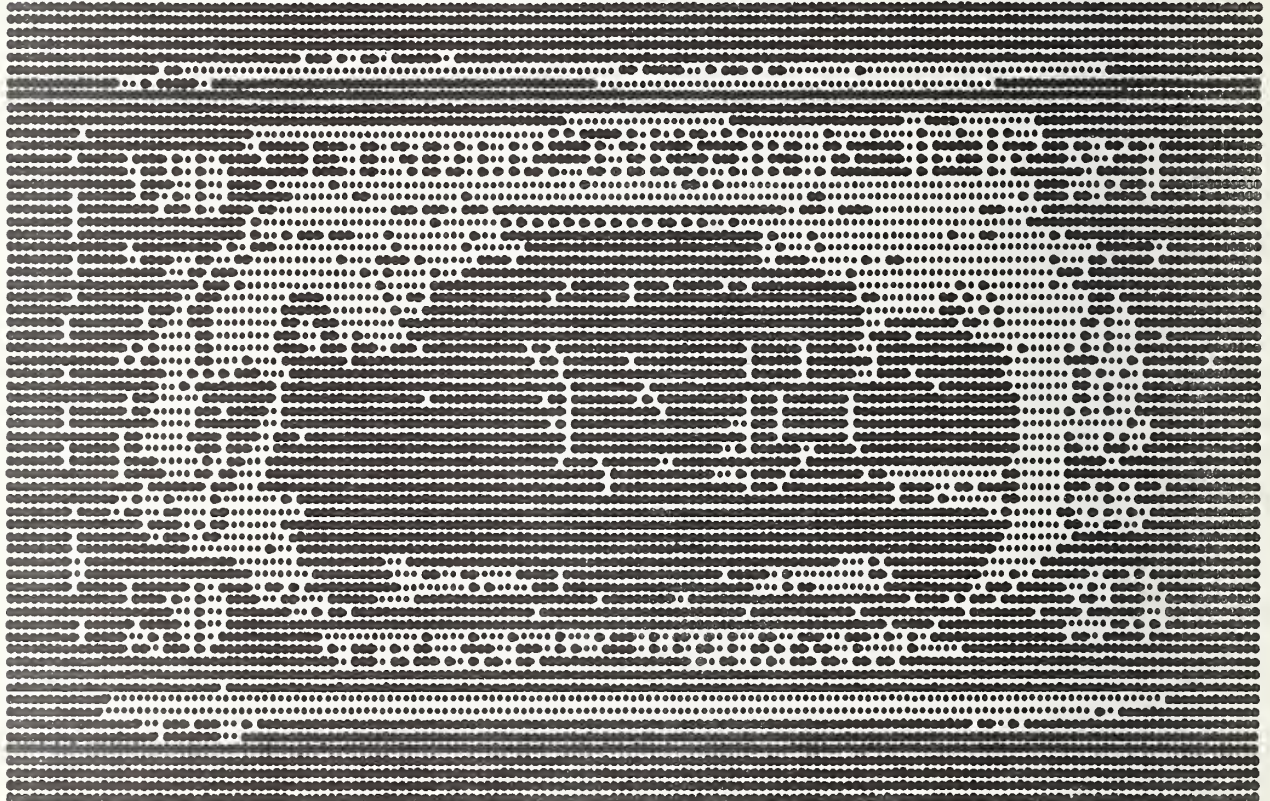
Figure 13. Computer printout showing where light from the images of the back sides of a ten and twenty dollar bill shine through a negative mask of the back side of a one dollar bill.

(A) MASK: FIVE   BILL: ONE

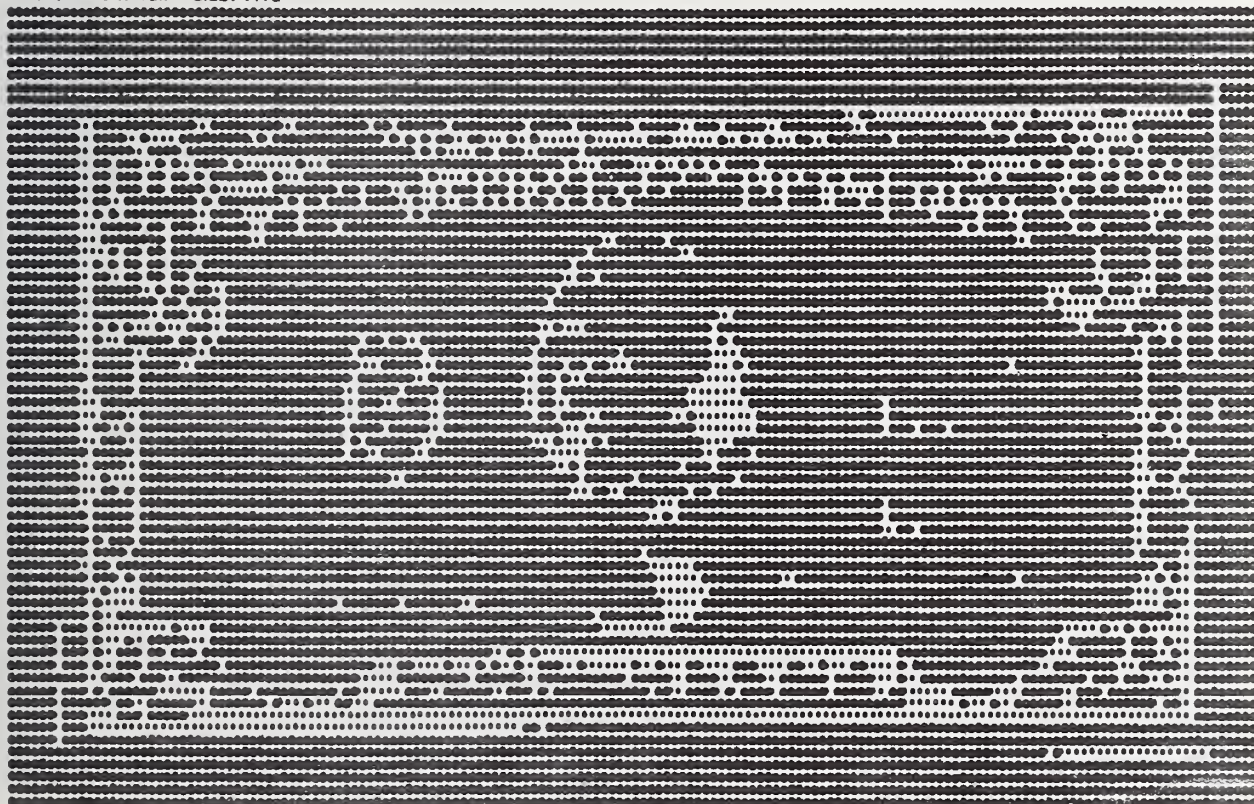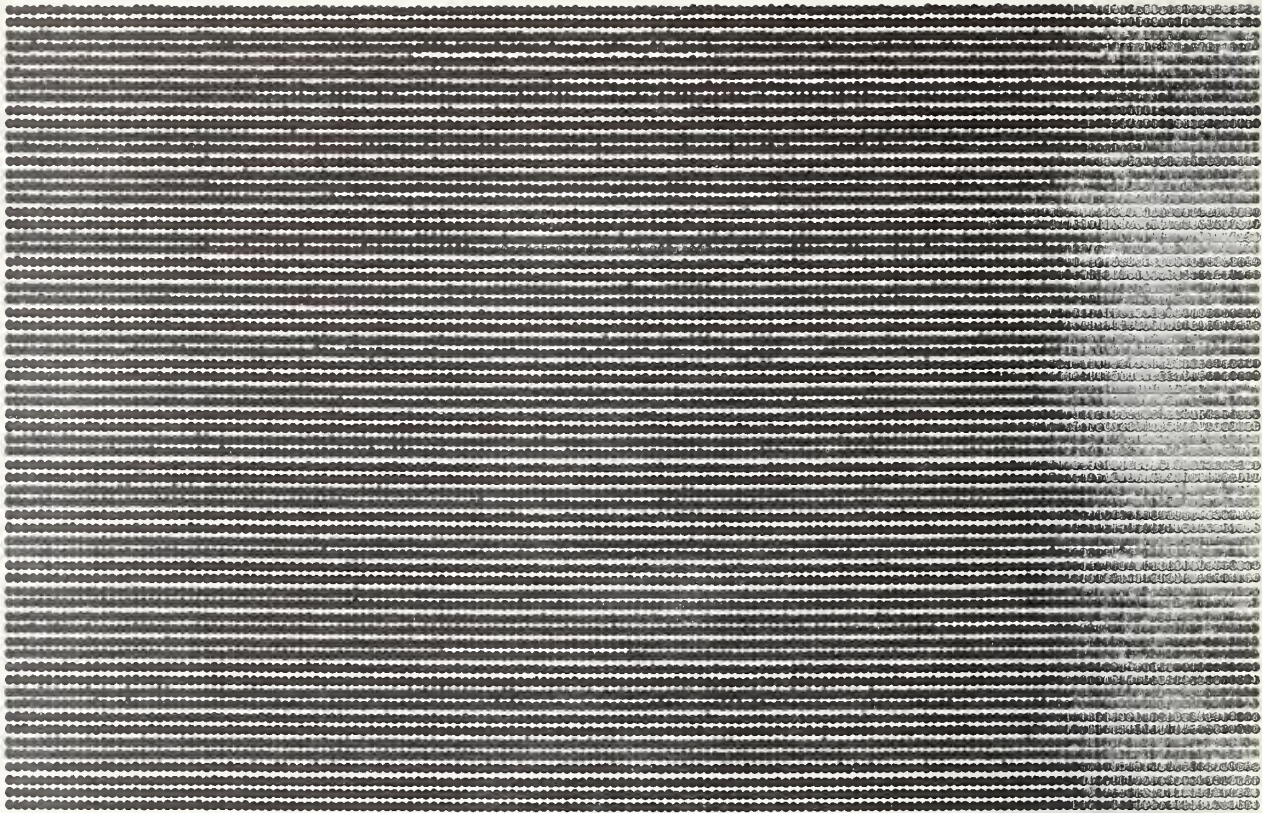**(B) MASK: FIVE   BILL: FIVE**

Figure 14. Computer printout showing where light from the images of the front sides of a one and a five dollar bill shine through a negative mask of the front side of a five dollar bill.
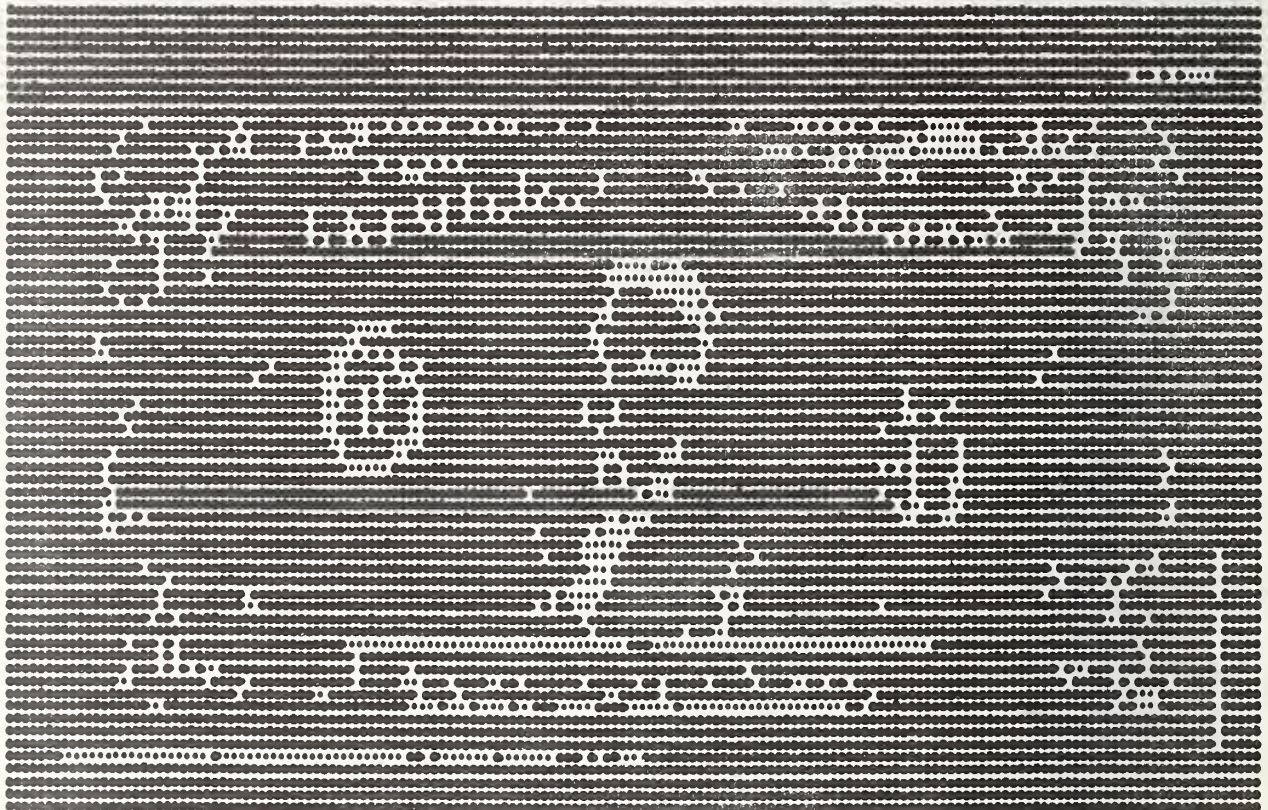
(A) MASK: FIVE   BILL: TEN
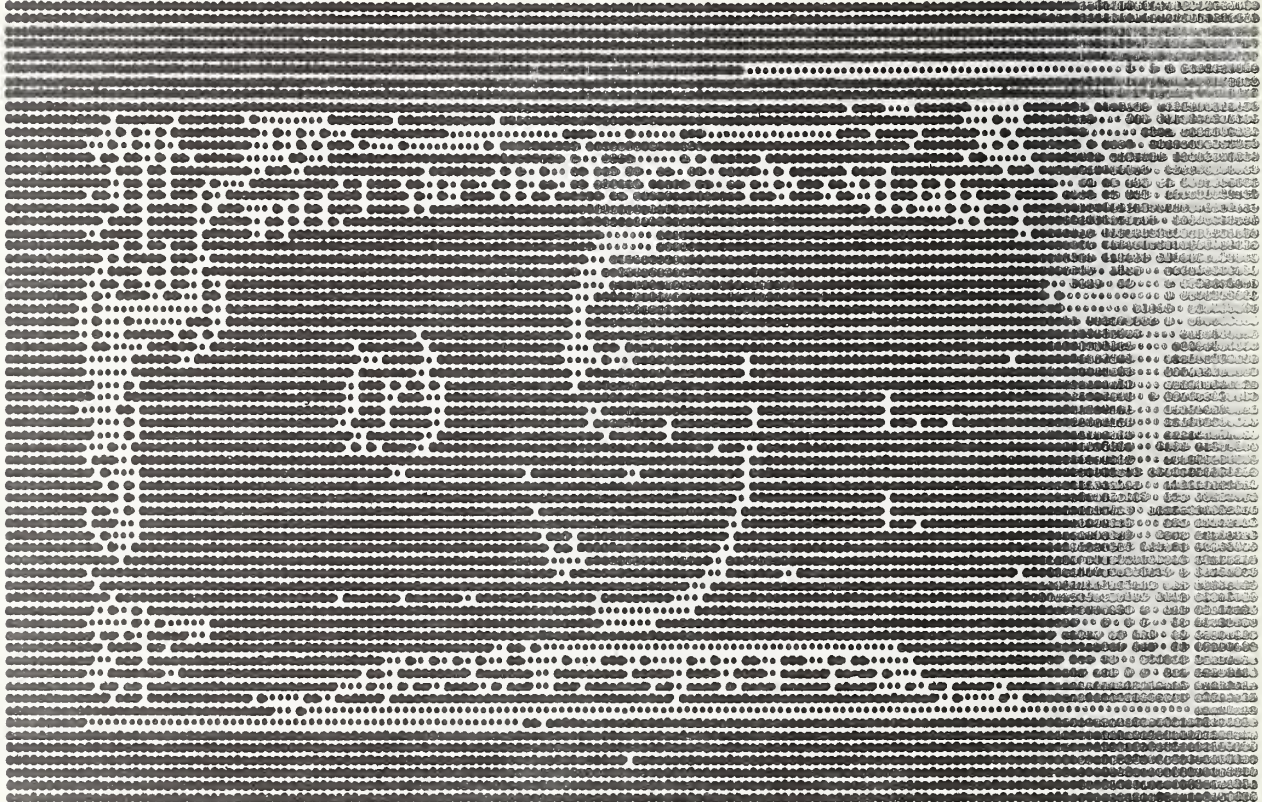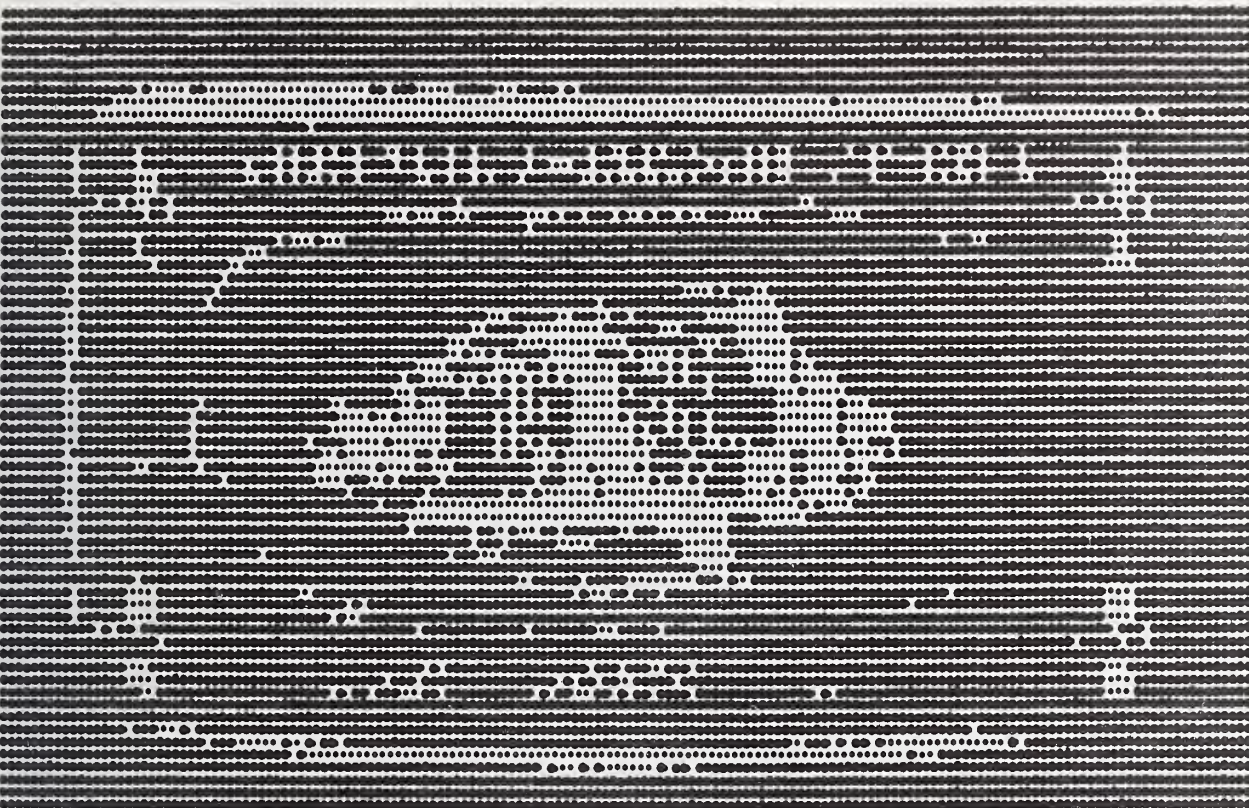
(B) MASK: FIVE   BILL: TWENTY
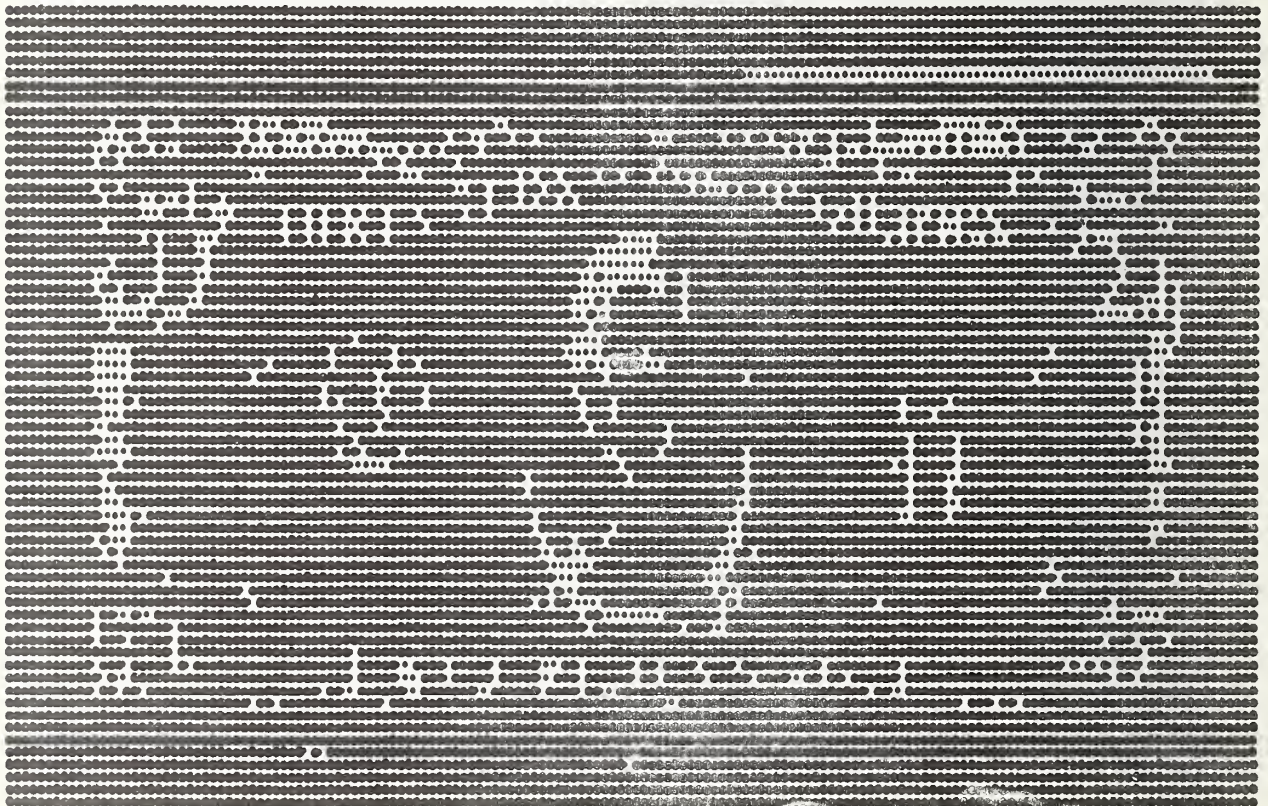
Figure 15. Computer printout showing where light from the images of the front sides of a ten and a twenty dollar bill shine through a negative mask of the front side of a five dollar bill.

(A) MASK: BACK 5   BILL: BACK 1
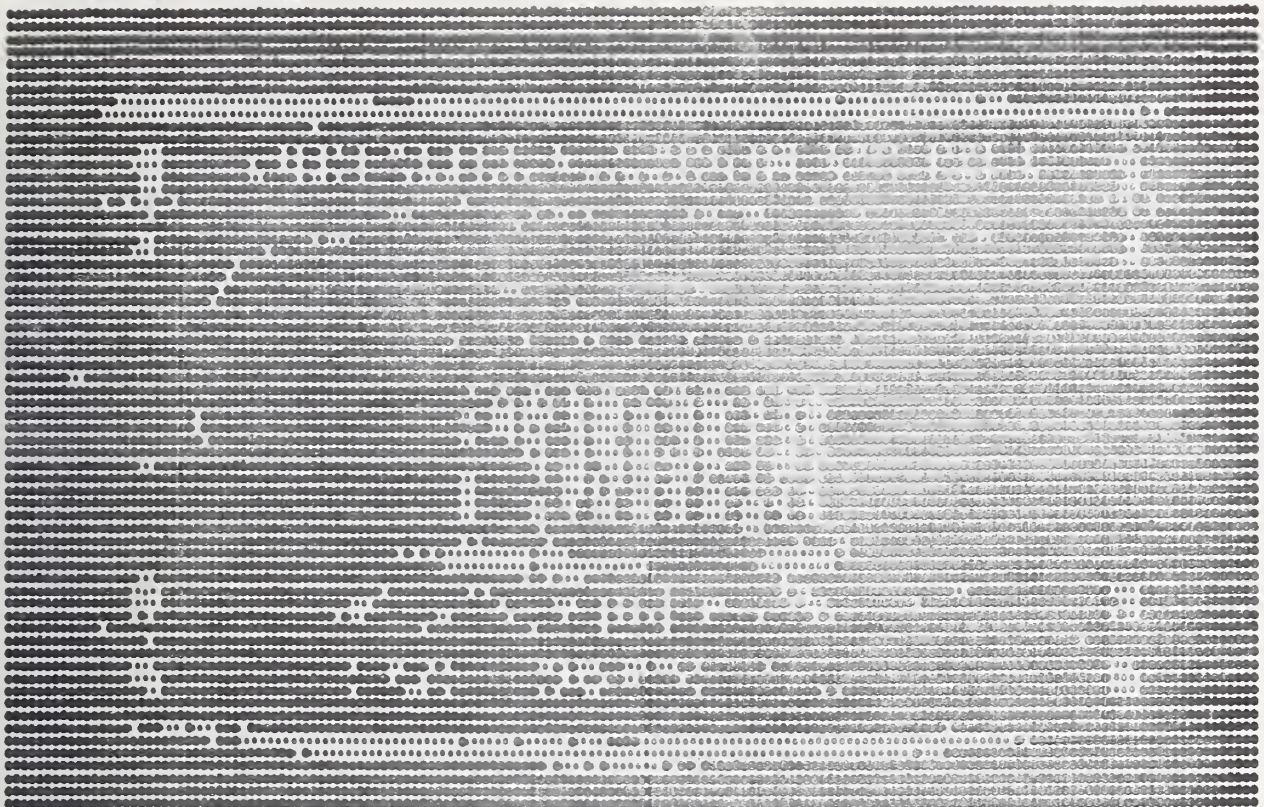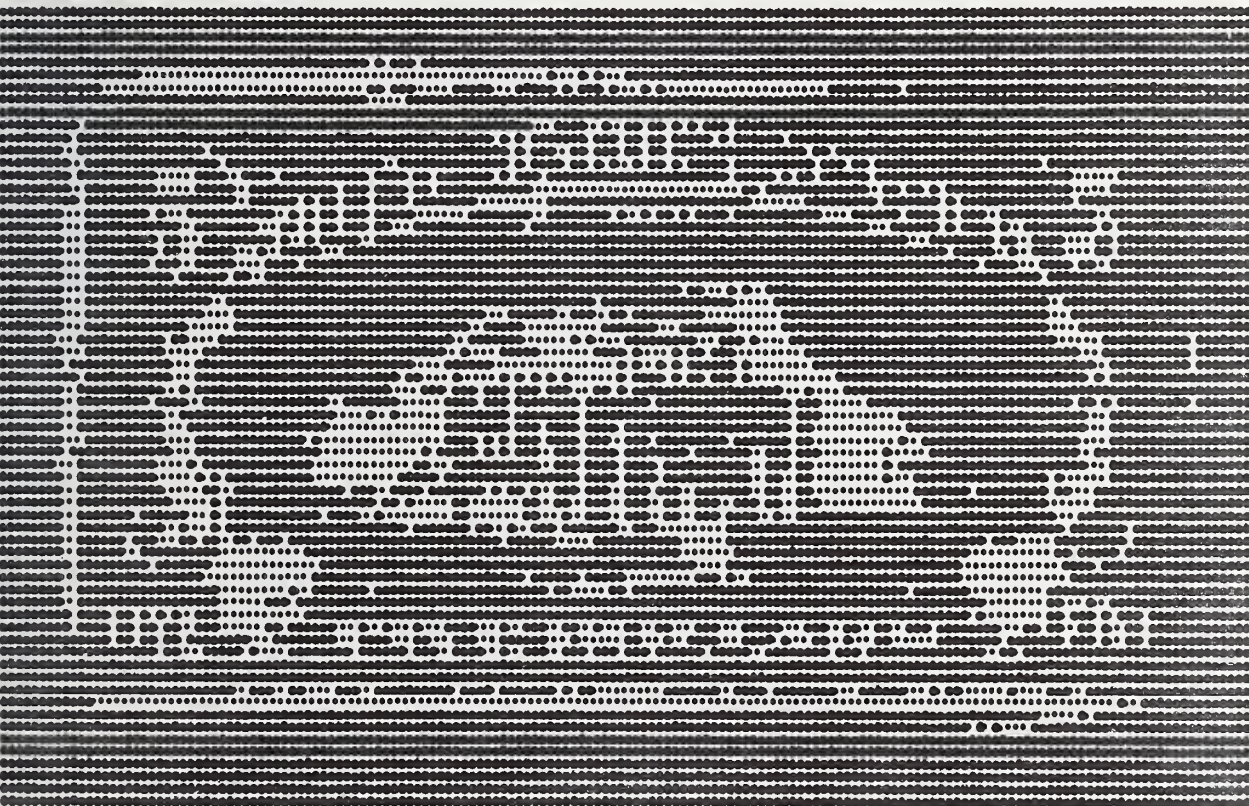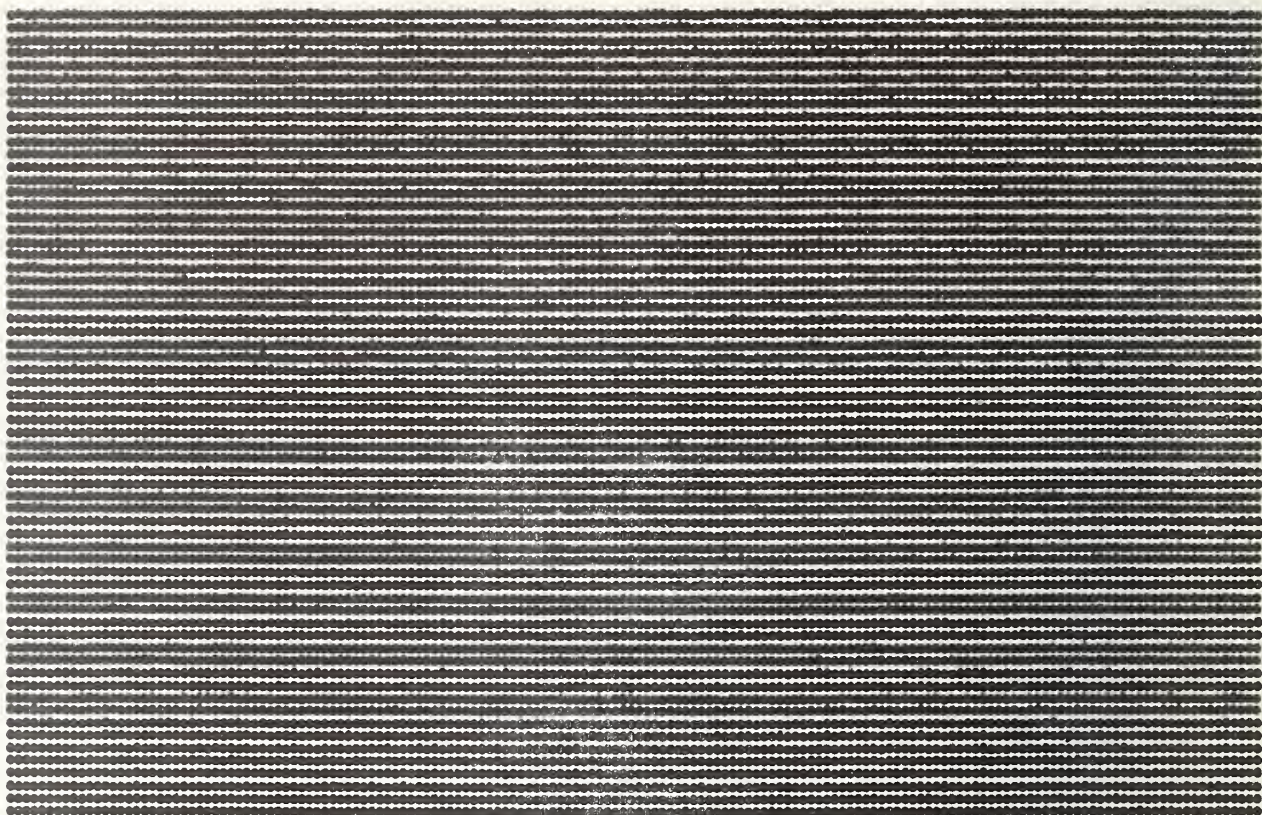

(B) MASK: BACK 5   BILL: BACK 5

Figure 16. Computer printout showing where light from the images of the back sides of a one and a five dollar bill shine through a negative mask of the back side of a five dollar bill.

(A) MASK: BACK 1   BILL: BACK 10

(B) MASK: BACK 5   BILL: BACK 20

Figure 17.   Computer printout showing where light from the images of the back sides of a ten and a twenty dollar bill shine through a negative mask of the back side of a five dollar bill.

(A) MASK: TEN   BILL: ONE

(B) MASK: TEN   BILL: FIVE

Figure 18.   Computer printout showing where light from the images of the front sides
of a one and a five dollar bill shine through a negative mask of the
front side of a ten dollar bill.

(A) MASK: TEN BILL: TEN
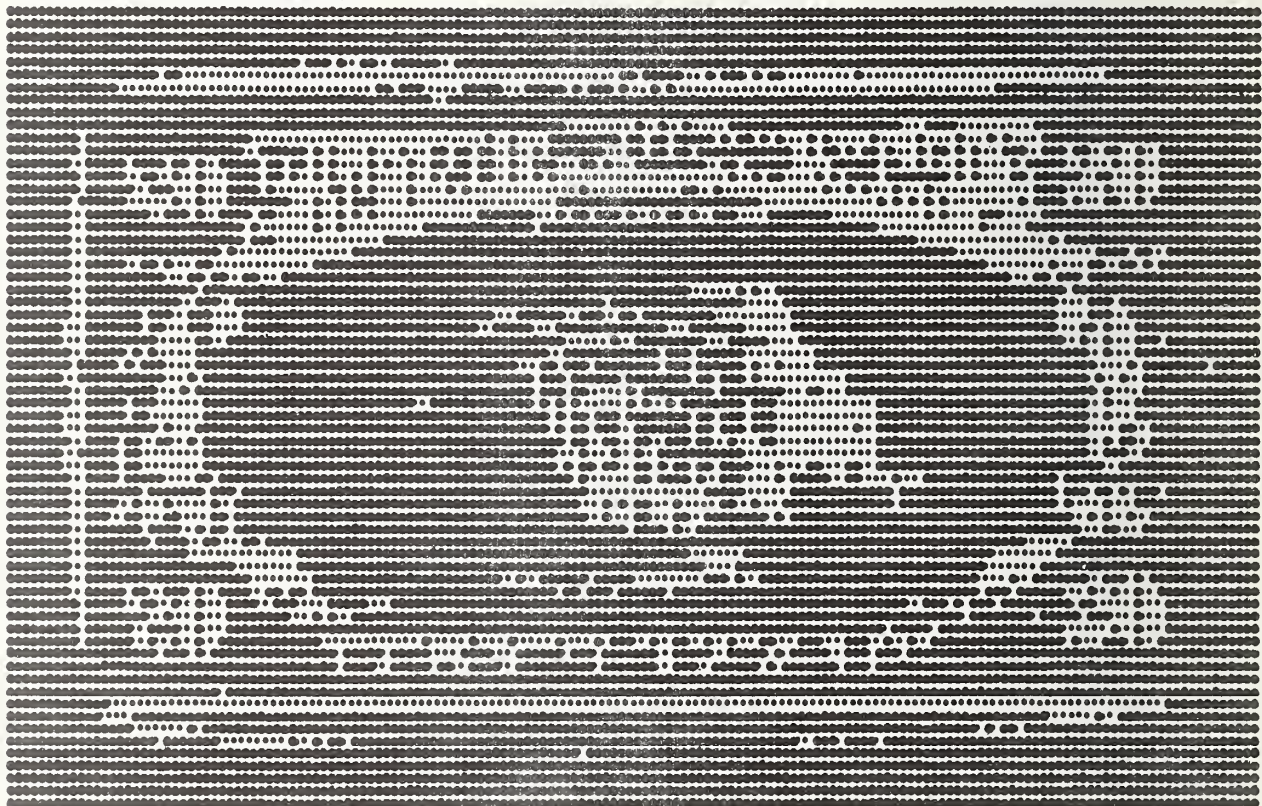

(B) MASK: TEN BILL: TWENTY

Figure 19. Computer printout showing where light from the images of the front
side of a ten and a twenty dollar bill shine through a negative mask
of the front side of a ten dollar bill.

(A) MASK: BACK 10   BILL: BACK 1

(B) MASK: BACK 10   BILL: BACK 5

Figure 20. Computer printout showing where light from the images of the back sides
of a one and a five dollar bill shine through a negative mask of the
back side of a ten dollar bill.

(A) MASK: BACK 10   BILL: BACK 10
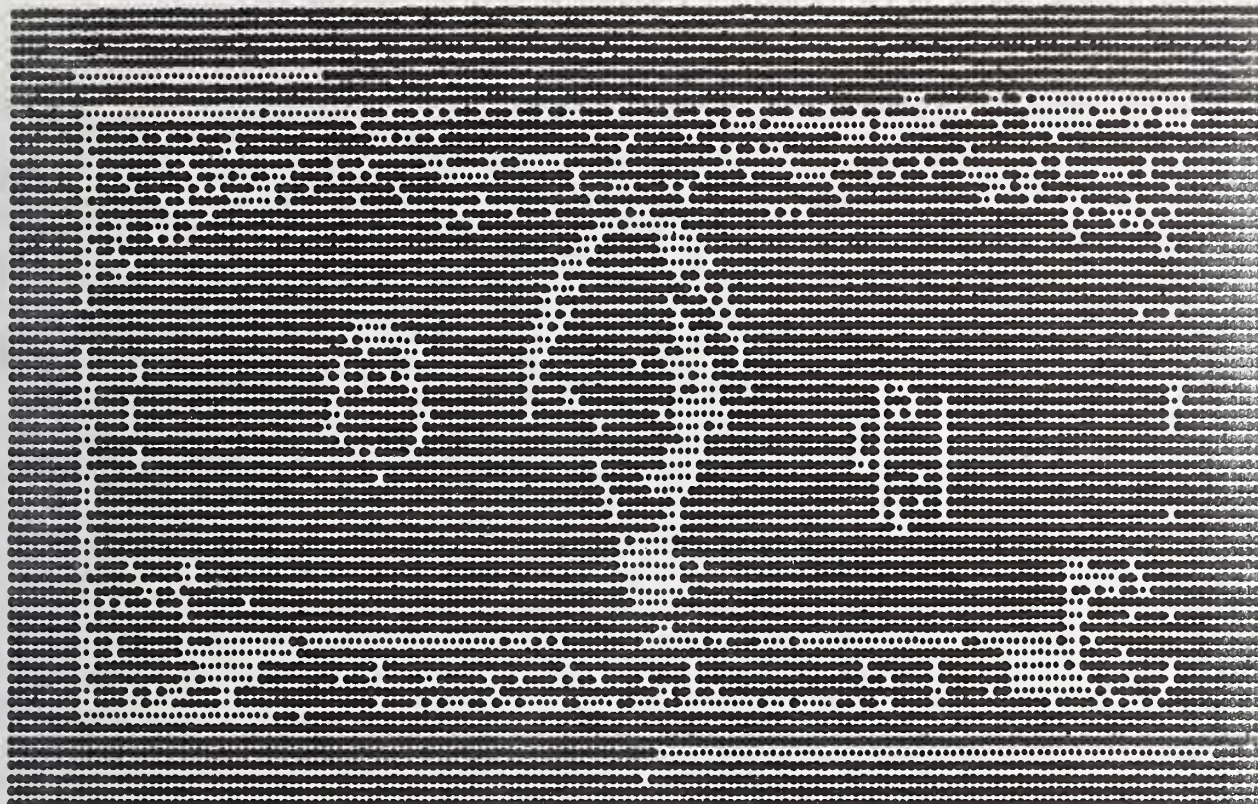
(B) MASK: BACK 10   BILL: BACK 20

Figure 21.   Computer printout showing where light from the images of the back side
              of a ten and a twenty dollar bill shine through a negative mask of the back
              side of a ten dollar bill.
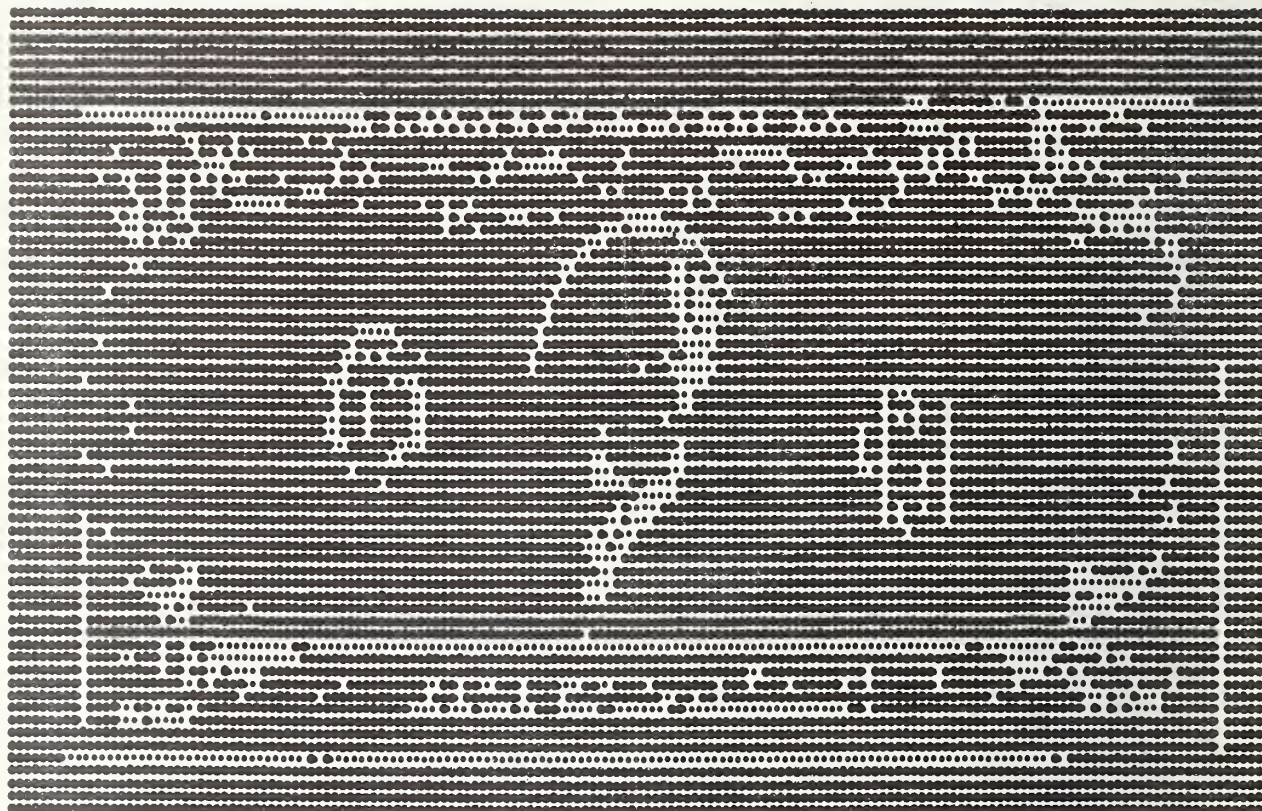
(A) MASK: TWENTY   BILL: ONE

(B) MASK: TWENTY   BILL: FIVE

Figure 22. Computer printout showing where light from the images of the front side
of a one and a five dollar bill shine through a negative mask of the front
side of a twenty dollar bill.

(A) MASK: TWENTY   BILL: TEN
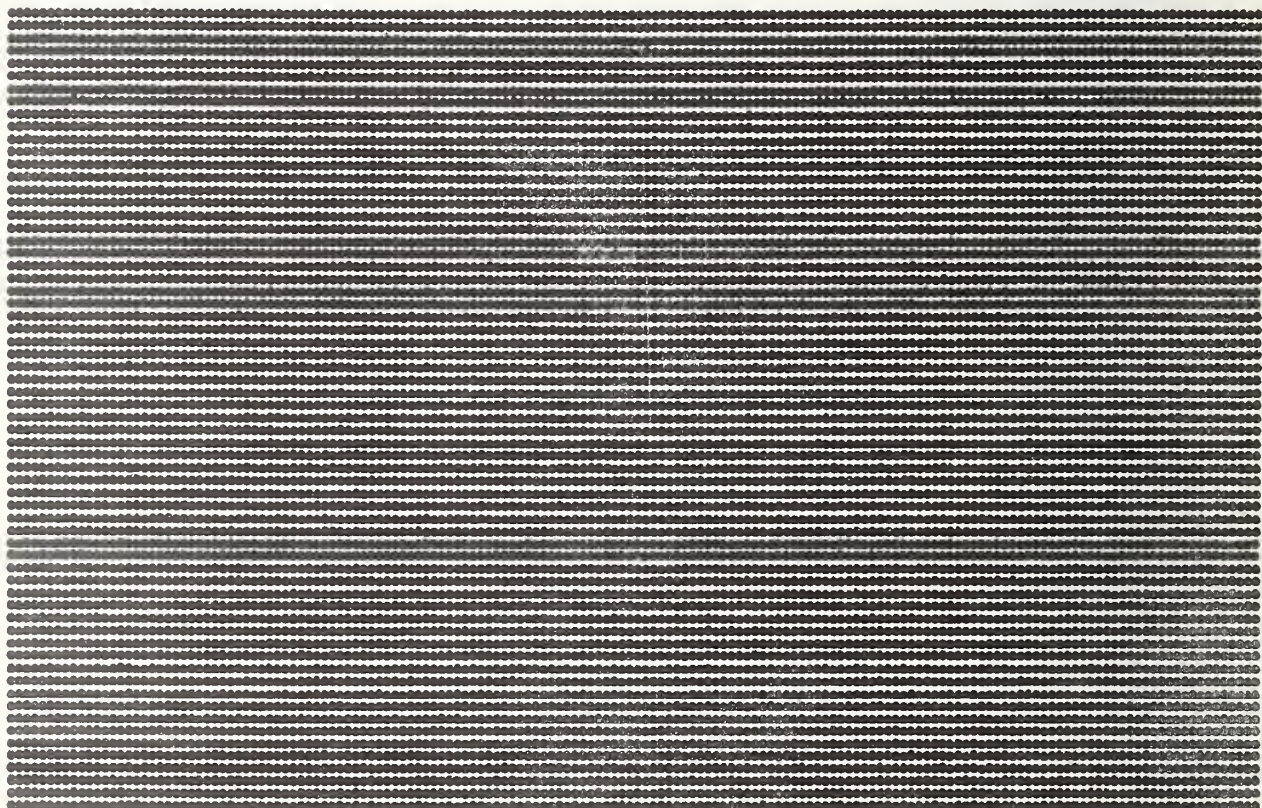
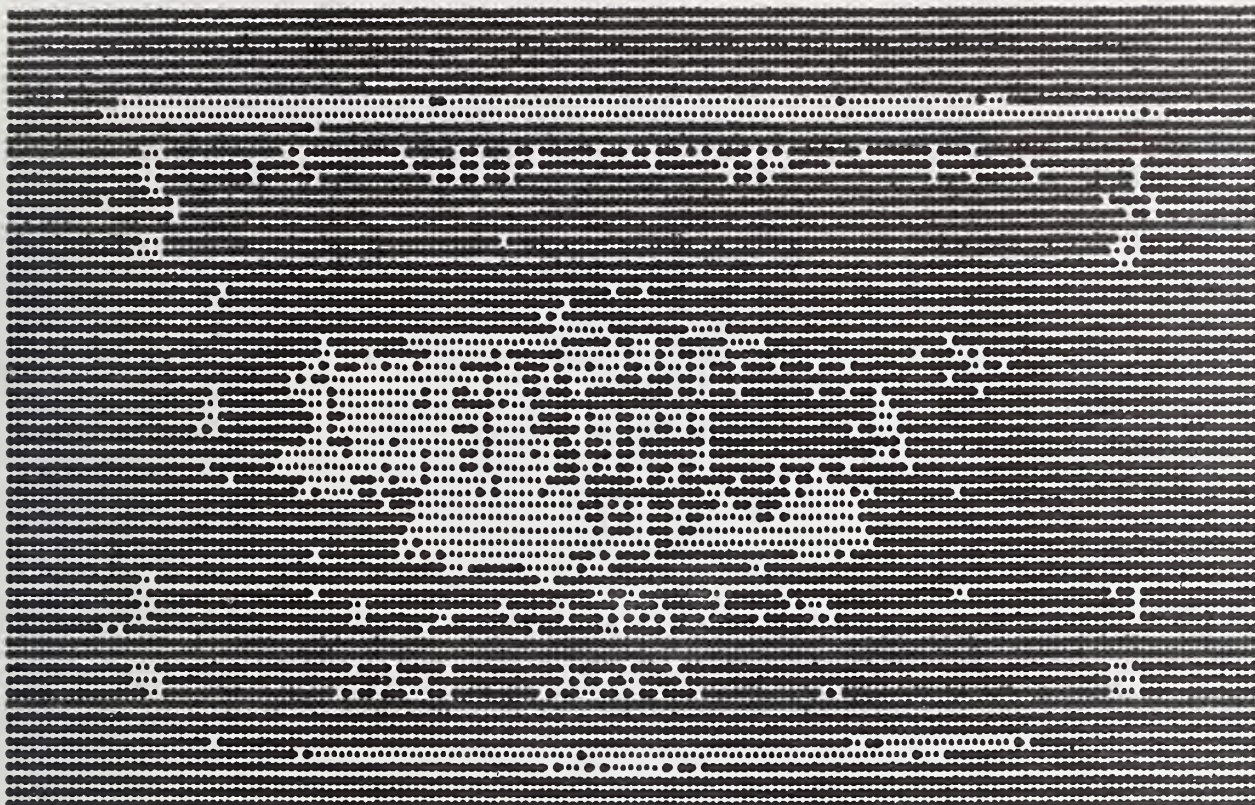(B) MASK: TWENTY   BILL: TWENTY

Figure 23. Computer printout showing where light from the images of the front sides
         of a ten and a twenty dollar bill shine through a negative mask of the front
         side of a twenty dollar bill.

(A) MASK: BACK 20   BILL: BACK 1

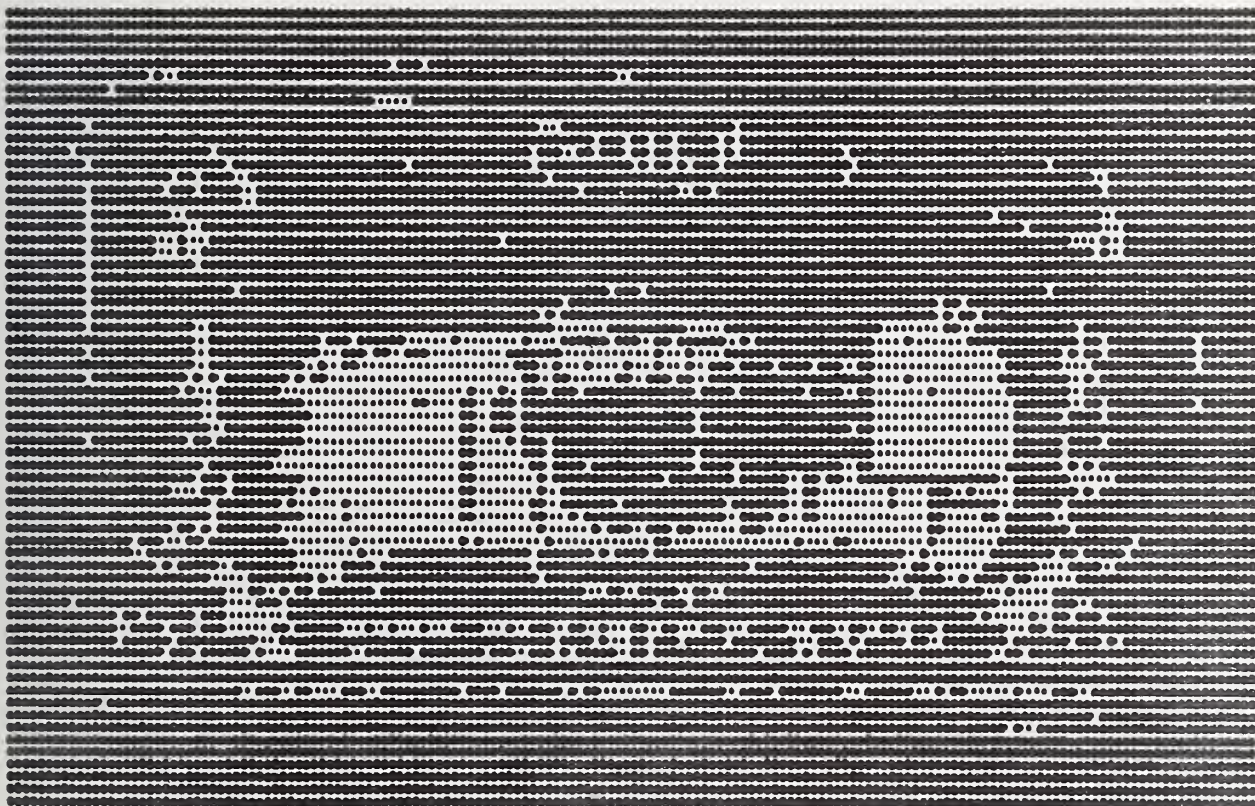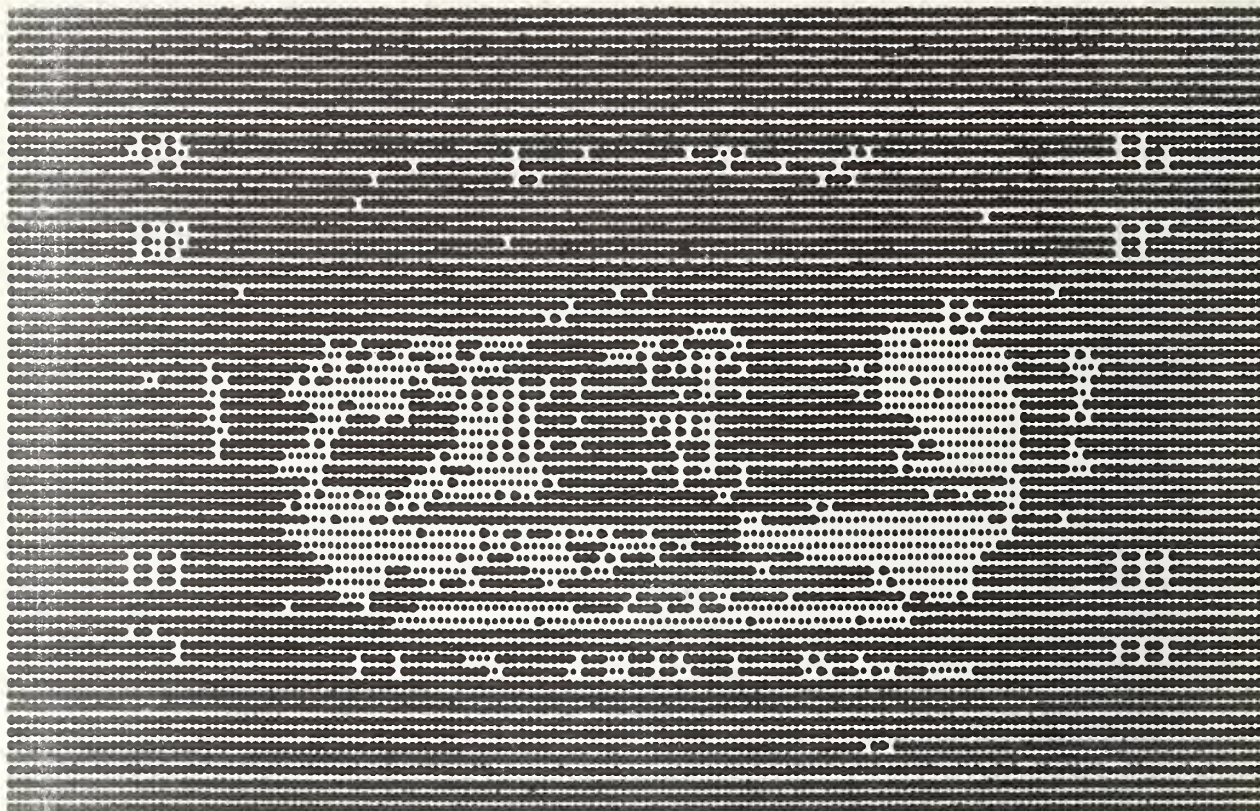(B) MASK: BACK 20   BILL: BACK 5

Figure 24. Computer printout showing where light from the images of the back sides
           of a one and a five dollar bill shine through a negative mask of the back
           side of a twenty dollar bill.

(A) MASK: BACK 20   BILL: BACK 10
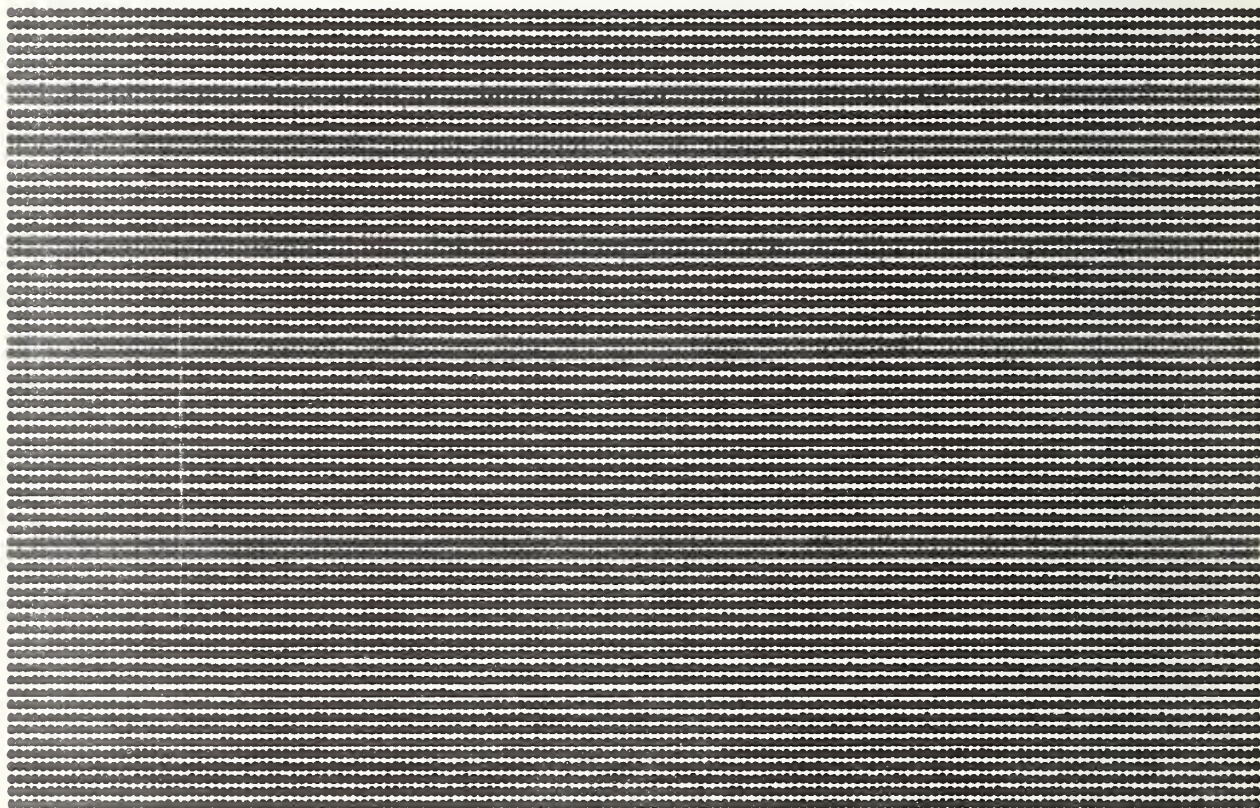

(B) MASK: BACK 20   BILL: BACK 20

Figure 25. Computer printout showing where light from the images of the back sides of a ten and a twenty dollar bill shine through a negative mask of the back side of a twenty dollar bill.

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

This report summarizes the progress on developing measurement methods necessary for the automatic handling of currency. It covers three areas of activity: 1) development of a method of detecting the presence of tape on a bill via thickness measurements, 2) development of a method of detecting the presence of tears, holes, or missing pieces and 3) work towards the development of a method of verifying the denomination of a bill. All these techniques are designed to assess bills while they are in motion through a transport system at rates up to twenty bills per second.

17. KEY WORDS (Alphabetical order, separated by semicolons)

Defect detection; fitness of currency; pattern recognition; thickness measurement

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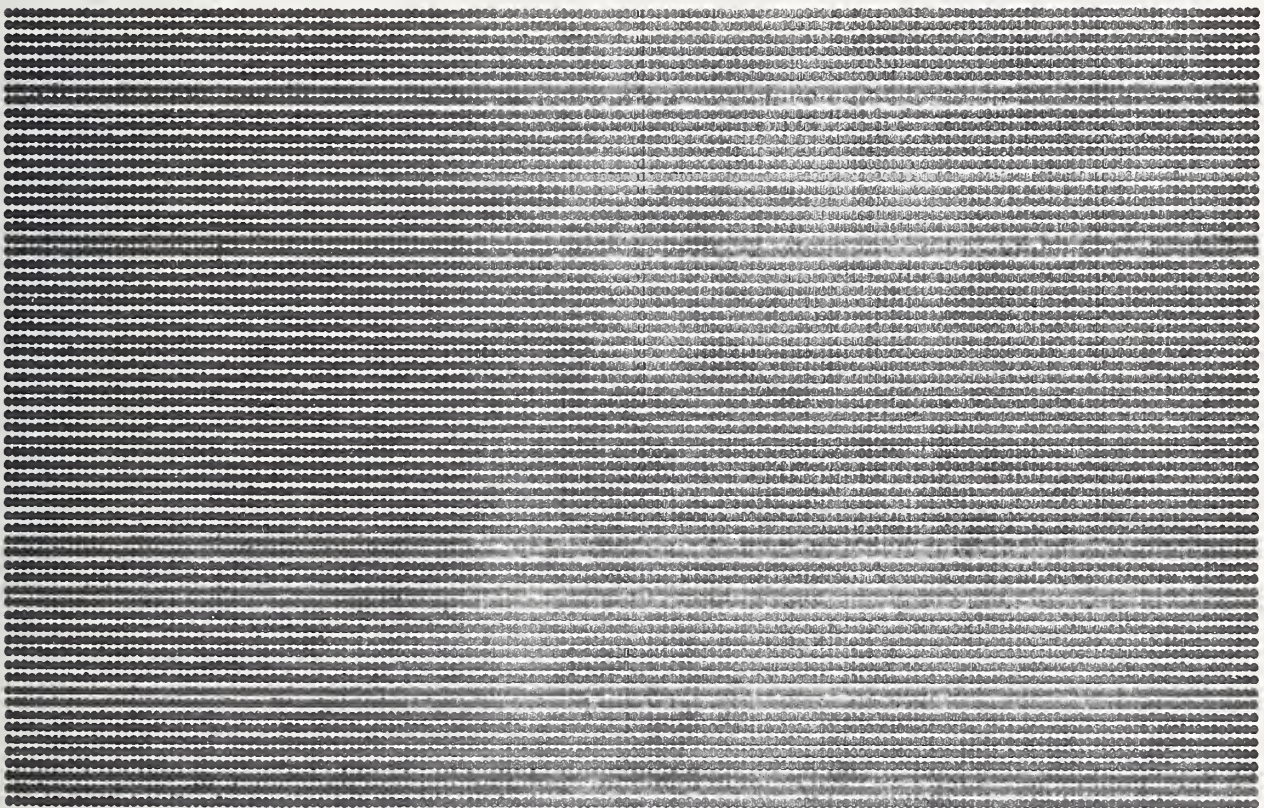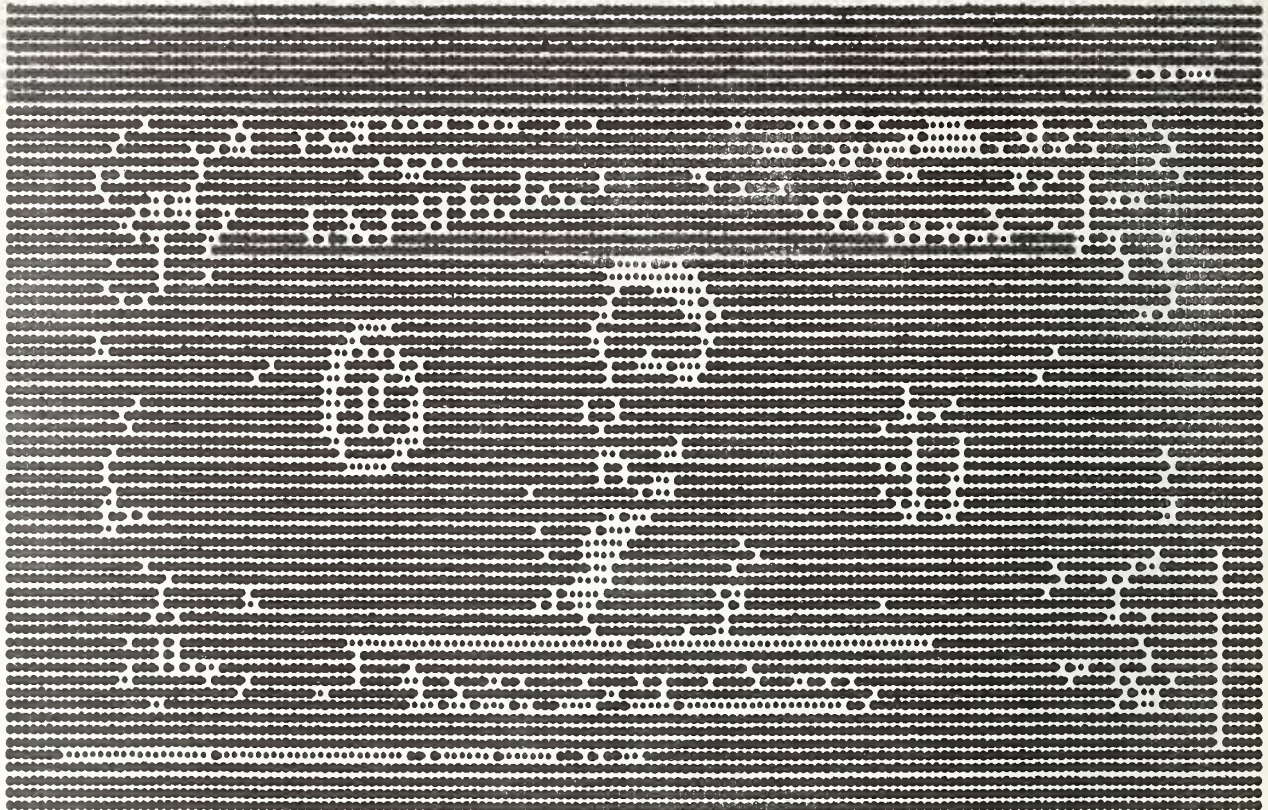

(B) MASK: FIVE   BILL: FIVE

Figure 14.   Computer printout showing where light from the images of the front sides
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side of a five dollar bill.

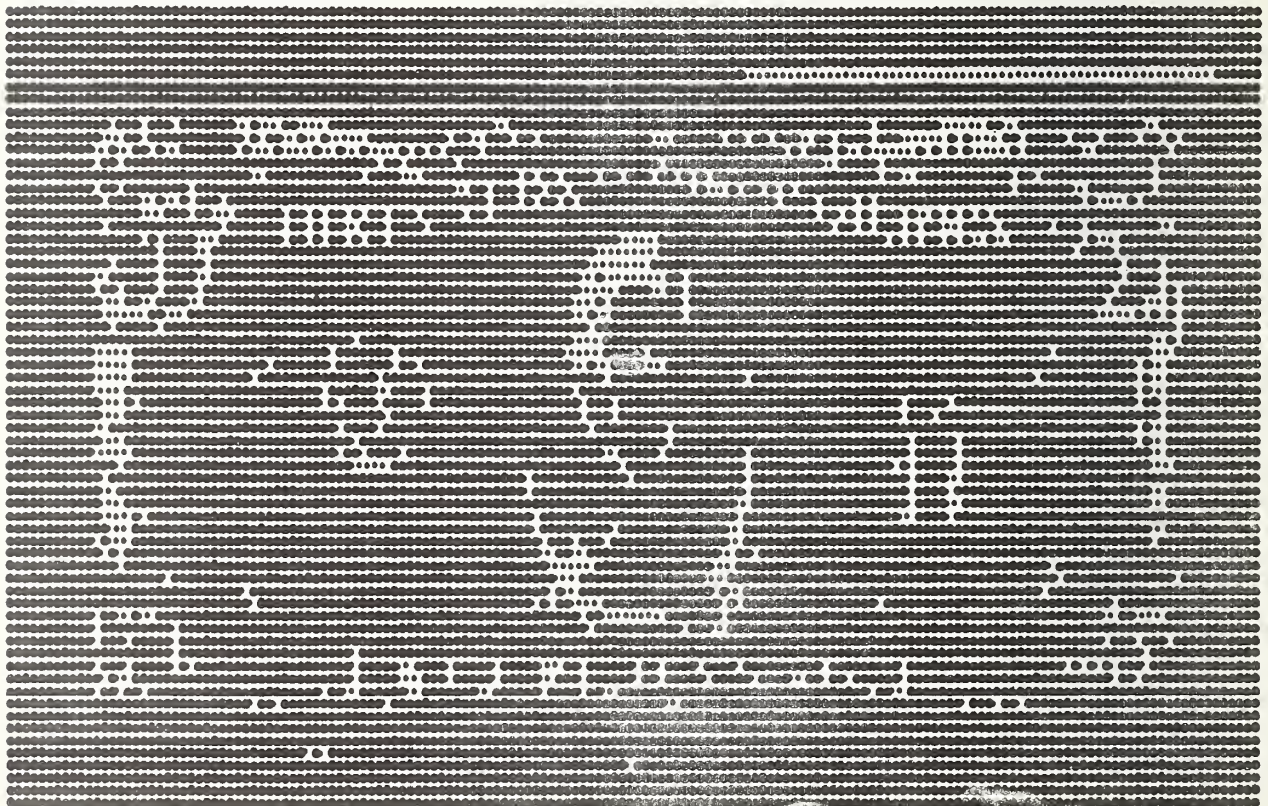(A) MASK: FIVE   BILL: TEN

(B) MASK: FIVE   BILL: TWENTY

Figure 15. Computer printout showing where light from the images of the front sides of a ten and a twenty dollar bill shine through a negative mask of the front side of a five dollar bill.